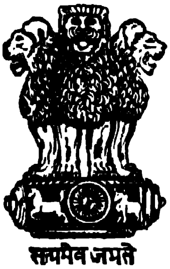

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SEARCHING OUT PLUTO—LOWELL'S TRANS-NEPTUNIAN PLANET X

By ROGER LOWELL PUTNAM and Dr. V. M. SLIPHER

LOWELL OBSERVATORY, FLAGSTAFF, ARIZONA

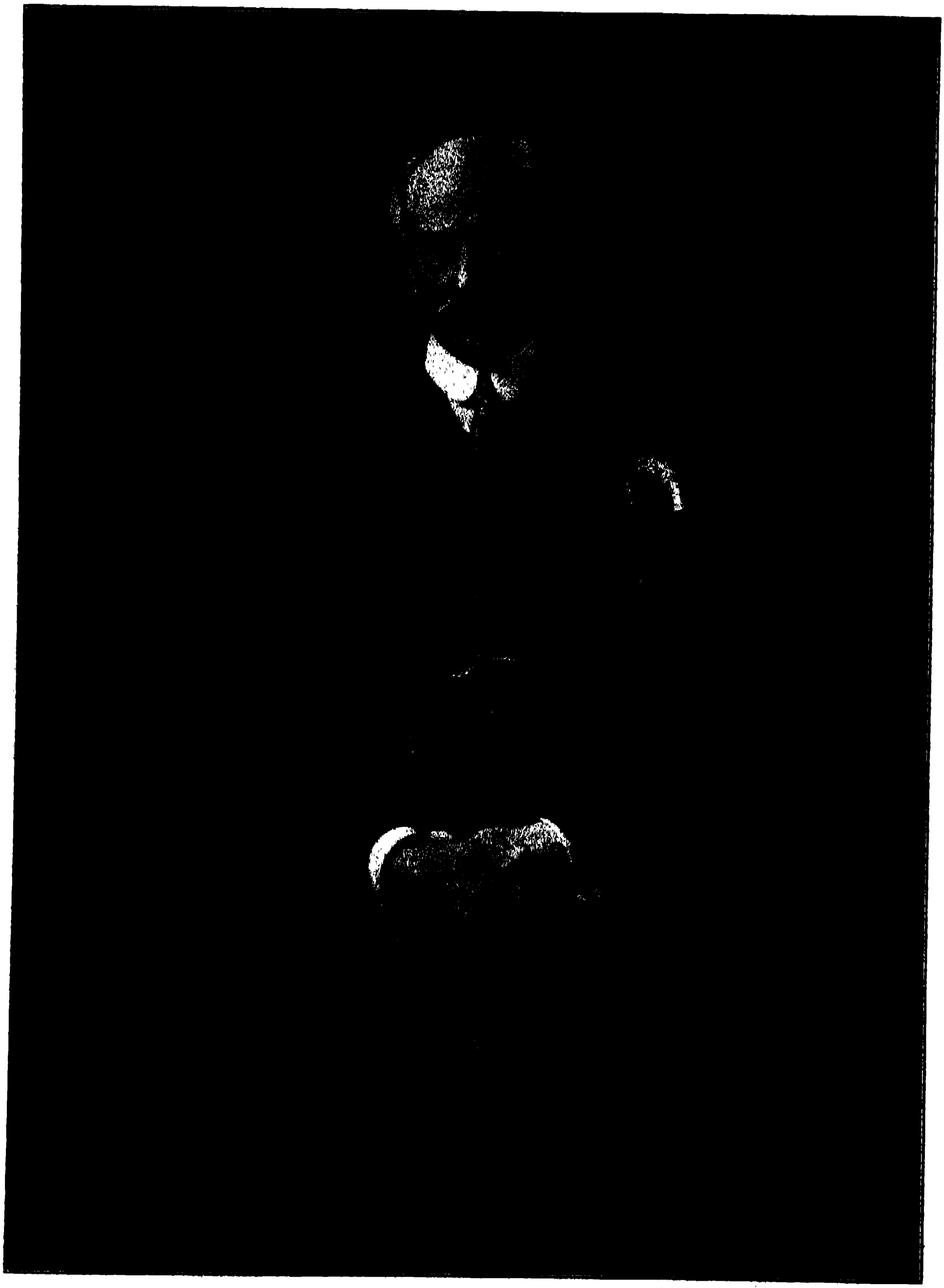
UNTIL the thirteenth of March, 1781, there had been only six known planets, including our own, and these had been known from time immemorial. Satellites of the major planets had been discovered, but to all intents and purposes the astronomical world thought that the solar system was complete.

On the night of March 13 of that year, however, Sir William Herschel, while patrolling the sky with his telescope, as was his habit, always alert to anything that might be seen, was struck by the appearance in the field of his instrument of an exceptional disk-like object. He at first thought that he had discovered a new comet, and, in fact, announced it as such, but it did not take many weeks' observation to show that it was a non-cometary body at great distance, and gradually he with others became persuaded that it was really a new planet that he had discovered. With rough calculations of the orbit, its course could be traced back, and it was found that it had actually been seen and its position had been plotted many times before, particularly by Lemonnier, but without its remarkable nature being recognized. These earlier positions with the new ones enabled a pretty exact orbit to be calculated.

Then after two thirds of a century came the remarkable discovery of Neptune, in 1846. Every one is now familiar with the work of Leverrier and Adams, who, starting with the then well-known fact that Uranus was deviating considerably from its computed orbit, quite independently calculated that clearly an outside planet must be disturbing it. They both almost simultaneously predicted where Neptune was to be found, and they have both received the credit, rather than Galle, who was first to observe it with the telescope.

At the beginning of this century, it began to be apparent that Neptune did not account for quite all the perturbations in the orbits of Uranus and Saturn. Various investigators attacked the problem, notable among whom was Dr. Percival Lowell, a great mathematician as well as a great astronomer, and this very difficult problem particularly appealed to him.

In his "Memoir on a Trans-Neptunian Planet," published in 1915, Dr. Lowell gave, in a little more than 100 pages and with little intimation of the years he had devoted to this difficult research, his results of the theoretical evidence of a planet beyond Neptune. This new member of the solar family he called Planet X. By way of introducing this subject, we can not do better than to quote some paragraphs from the beginning and the conclusion of his now classical Memoir:



DR. PERCIVAL LOWELL (1855–1916)

EMINENT AMERICAN ASTRONOMER, WHO MATHEMATICALLY PROVED YEARS AGO THE EXISTENCE OF THE NEWLY DISCOVERED PLANET PLUTO AND LIKEWISE SHOWED WHERE IT WAS TO BE FOUND IN THE SKY. HE FOUNDED, DIRECTED AND ENDOWED THE LOWELL OBSERVATORY, FLAGSTAFF, ARIZ.

> Ever since celestial mechanics in the skillful hands of Leverrier and Adams led to the world-amazed discovery of Neptune, a belief has existed begotten of that success that still other planets lay beyond, only waiting to be found. Leverrier, himself, with the far-sight of genius, was firmly of this view, though unfortunately over-sanguine of the happy date of its demonstration. In consequence, since his time, many attempts have been made to indicate the position of one or more of these unknowns, attempts for the most part, of no scientific value because not founded on rigorous mathematical investigation. For so complicated is the problem that all elementary means of dealing with it lead only to error. The sole road to any hope of capture lies through the methodical approach of laborious analysis.
>
> Not only are all summary processes worse than useless, engendering false ideas in their conclusions, even a supposed proximate analysis proves not to be approximate in its results. Thus the simplifying of the problem by the assumption of a circular orbit for the unknown, originally suggested by Tisserand and worked out in the present case with all due reserve by M. Gaillot, and more or less likewise by M. Lau, betrays intrinsic evidence of inadequacy. . . .
>
> 2. To any real solution, the problem must be attacked analytically with all the rigor possible. Before entering upon such an investigation, it is well to state the problem generally, showing the data upon which it rests, and the limitations to which it is necessarily subject. For lack of appreciation of these points has led to mistaken ideas of what is or is not possible.
>
> 3. The theory of a planet can not in the nature of things be exact; and this for three reasons:
>
> (1) The observations on which it is founded are necessarily more or less in error;
>
> (2) The theory, itself, may be more or less imperfect;
>
> (3) An unknown body may be acting of which perforce no account has been taken. . . .

Then quoting from the conclusion:

> In the next place, the solutions, themselves, tell us of alternatives between which they leave us in doubt to decide. If we go by residuals alone, we should choose those solutions which have their mean longitudes at the epoch in the neighborhood of 0°, since the residuals are there the smallest. But on the other hand, this would place the unknown now and for many decades back in a part of the sky which has been most assiduously scanned, while the solutions with ε' around 180° lead us to one nearly inaccessible to most observatories, and, therefore, preferable for planetary hiding. . . .
>
> Owing to the inexactitude of our data, then, we can not regard our results with the complacency of completeness we should like. . . .
>
> . . . Analytics thought to promise the precision of a rifle and finds it must rely upon the promiscuity of a shot gun after all, though the fault lies not more in the weapon than in the uncertain bases on which it rests. . . .
>
> 8. The investigation disclosed two possible solutions in each case, one with ε' around 0°, one with it around 180°; and that this duality of possible place would necessarily always be the case.
>
> 9. On the whole, the best solutions for the two gave:
>
> | Longitude .... | | around 0° | | around 180° |
> |---|---|---|---|---|
> | Long. Perihelion | = | 22.°1 | = | 205.°0 |
> | Semi-major axis | = | 43.0 | = | 44.7 |
> | m' ...... | = | 1.00 | = | 1.14 |
> | e' .... | = | .202 | = | .195 |
> | Argument of Perihelion ..... | = | 203.°8 | = | 19.°6 |
> | hel. long. July 0, 1914 ..... | | 84.°0 | | 262.°8 |
>
> the unit of m'... $= \frac{1}{50,000}$ the mass of the sun.
>
> 10. It indicates for the unknown a mass between Neptune's and the Earth's; a visibility of the 12–13 magnitude according to albedo; and a disk of more than $1''$ in diameter.
>
> 11. From the analogy of the other members of the solar family, in which eccentricity and inclination are usually correlated, the inclination of its orbit to the plane of the ecliptic should be about 10°. This renders it more difficult to find.
>
> 12. Investigations on the perturbation in latitude yielded no trustworthy results. This is probably because the eccentricity of e' as well as the planet's other elements enter as data into the latitude observation equations.
>
> 13. The perturbative function is not discontinuous at the commensurability of period points, a fact hitherto in doubt.
>
> 14. That when an unknown is so far removed relatively from the planet it perturbs, precise prediction of its place does not seem to be possible. A general direction alone is predicable.

Thus Dr. Lowell found two regions of the ecliptic in diametrically opposite quarters of the sky, either of which might contain the trans-Neptunian planet. Yet it will be noted that his equations actually were a little more favorable to the position in which the

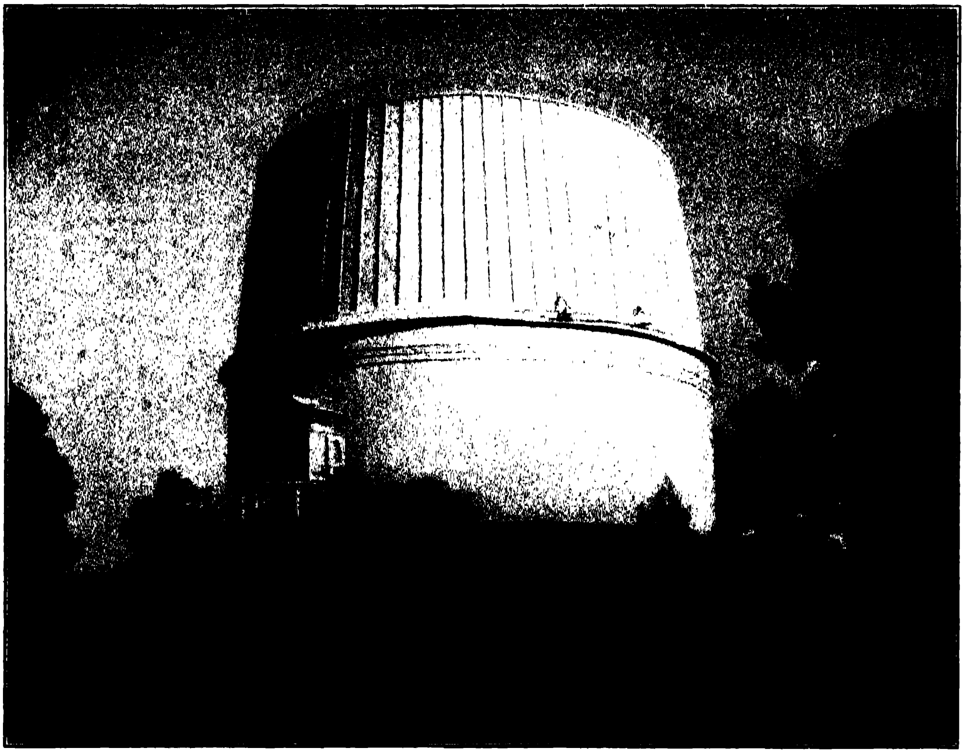


FIG. 1. THE DOME OF THE LARGE VISUAL TELESCOPE
THE FIRST UNIT OF THE LOWELL OBSERVATORY'S GROUP OF TELESCOPES.

planet was finally found. While this work was not completed and published until 1915, it was begun more than a decade earlier, and he had indeed found indications of the existence of the new planet as early as 1905. So encouraging were his theoretical findings, even then, that the preliminary steps on the search for the planet were taken under his direction that year. The interesting coincidence should here be pointed out that weak images of his Planet X were actually recorded on two plates made here the same year, 1915, that he made public his theoretical predictions, and were found last June by E. C. Slipher, aided by the known path of the planet.

It was early realized that to find the planet among the numerous stars only the methods of photography properly utilized could cope with the difficulties of the problem. It was clear that the method of procedure was to make two or more photographs of each small area of sky, at intervals of a few nights. These duplicate plates would then be carefully compared in such manner as to cause the predicted planet, when recorded on the plates, to reveal its presence by its shifting its position relative to the multitudes of stars, owing to its moving during the interval between the taking of the two plates.

After having some preliminary test exposures made, in 1905, by J. C. Duncan, Dr. Lowell procured from the John A. Brashear Company a special five-inch aperture photographic objective which, on a mounting assembled from available instrumental essentials by C. O. Lampland, gave good results.

Under Dr. Lowell's direction about

two hundred plates were secured with this 5-inch camera by E. C. Slipher in 1906 and 1907, and 50 odd by K. P. Williams, in the summer of 1907. This series covered the entire circuit of the sky centered along the invariable plane (the mean orbit plane of the planets), duplicate plates being made every 5°. The exposure times of the plates were of about three hours' duration in order to have the plates reach sufficiently faint stars—below the 16th magnitude (*i.e.*, ten magnitudes fainter than the unaided eye sees). The camera gave very sharp star images, but the size of field of sharp definition was small compared with those of the improved lenses of to-day.

Dr. Lowell examined these plates, but unfortunately he then had no suitable means for the purpose, and it was a very difficult task. The examination of such plates, even with the highly efficient means to-day, is much more time-consuming and difficult than the making of the plates.

The photograph in Fig. 5 shows a portion of one of the plates which often have more than 100,000 stars on a single plate. The degree of carefulness of the examination will be appreciated when it is stated that the plates must be examined so carefully that the image of the moving Planet X could only be singled out by its motion relative to the thousands of stationary stars on the plates.

Later the Hartmann comparator, intended for small spectrum plates, was enlarged and modified to make it serve for the sky plates, and was used by Lowell with some advantage over the hand magnifier methods he first employed. In his searching of these plates, his hopes were occasionally aroused by the behavior of an exceptional asteroid resembling temporarily that of a much more distant body.

After this considerable period of painstaking work with the Brashear camera, it became evident that an instrument of more power and larger field was needed. And also that an efficient comparator was required for the critical and expeditious examination of the plates. He then secured a Zeiss Blink comparator, which greatly facilitated the comparison and examination of the plates thereafter.[1]

Dr. Lowell next had an extensive series of plates made with the 42-inch reflector by C. O. Lampland and E. C. Slipher, aided by other members of the staff. With this powerful instrument, the requisite exposure time of the plates was comparatively short (less than ten minutes) and they still included sufficiently faint 17th magnitude stars. Thus the plates could be accumulated very rapidly. However, the smallness of the field of these plates with the large reflector meant that a few thousand of them were made and needed to cover even a moderate area of sky. Their examination, unfortunately quite a burdensome task, even with the efficient Blink instrument, was first carried on by Dr. Lowell, himself, and later by C. O. Lampland, who has published a considerable list of asteroids and variables found on these plates by himself and E. C. Slipher.

These years of searching, with the reflector, further emphasized the need of a wide-field, photographic telescope of considerable light-power. The ordering of such an instrument was planned, but Dr. Lowell was eager to keep pressing forward with the search, because of the encouraging results his theoretical investigations had yielded.

Fortunately, it was possible, through the kind interest of Dr. John A. Miller,

---

[1] Later, in 1919, those plates neighboring the place predicted by Dr. Lowell's Memoir were examined in the Blink comparator by E. C. Slipher, but we know now that the inclination of the new planet's path placed it just off the south edge of these plates.

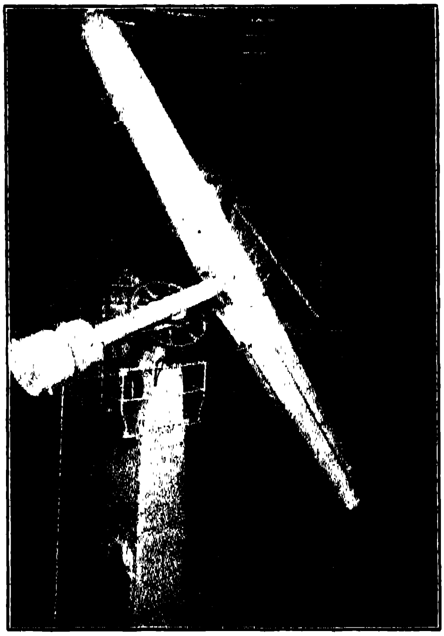


FIG. 2. THE LARGE LOWELL REFRACTING TELESCOPE

FAMOUS FOR STUDIES OF THE PLANETS AND FOR REVEALING THE ENORMOUS SPEEDS OF THE NEBULAE.

director of Sproul Observatory, to have the use for a time of that observatory's new photographic telescope. This instrument of 9 inches aperture by Brashear was used at Flagstaff from 1914 to 1916, and a large number of plates made with it, under Dr. Lowell's direction, chiefly by T. B. Gill and E. A. Edwards, supervised by C. O. Lampland. Only a partial examination of these plates was made by Lowell. Later Mr. Lampland surveyed the plates for asteroids and variables and listed 515 asteroids and 700 variable stars.

In the meantime the advent of the war had postponed the day when the new instrument could be had for the searching. This was no small disappointment to Dr. Lowell, coming at a time when he felt that theory had done all it could do, and the finishing of the task was clearly an observational one. And also he realized his Memoir would suggest the problem to other observatories then better provided instrumentally than was his, for the search.

But the result of his labors he was not to see come to full fruition, for, in 1916, death deprived the observatory of its founder and able leader, and further search for his Planet X had to be held in abeyance until a suitable instrument might be available.

In 1925, the glass disks for a 13-inch objective were offered for sale by the widow of the late Rev. Joel Metcalf. Though these disks were for an objective smaller than had been tentatively planned for the search, V. M. Slipher suggested to Mr. Guy Lowell, then trustee of the Lowell Observatory, that they would make an instrument which would serve at least greatly to advance the search for the planet, which Dr. Lowell's equations promised was waiting in the sky to be picked out from among the

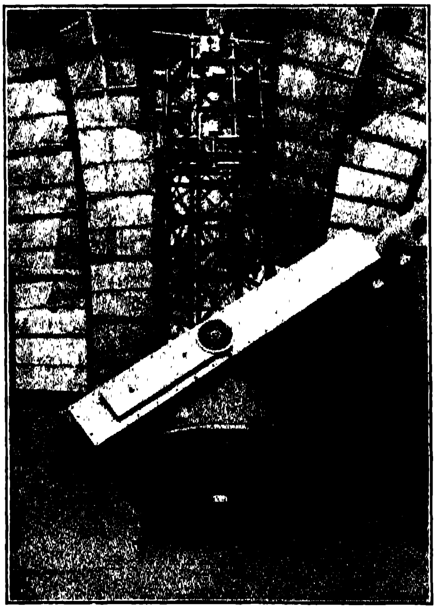


FIG. 3. THE 42-INCH REFLECTOR

WHICH HAS GIVEN EXCELLENT RESULTS IN THE PHOTOGRAPHY OF STARS, NEBULAE AND PLANETS, AND IN RADIOMETRIC WORK ON THE PLANETS.

stars. Mr. Guy Lowell, becoming deeply interested in the 13-inch glass disks and the prospect they offered for the much-needed instrument, personally purchased the glass, and went about planning to convert the rough-ground disks into a finished lens. Then, just as he was finding opportunity to touch more intimately the scientific problems of the observatory, he was overtaken by death, early in 1927.

Shortly thereafter the necessary money to complete the instrument and its mounting was generously provided by Dr. Percival Lowell's brother, President A. Lawrence Lowell, of Harvard. The making of the large objective was entrusted to C. A. R. Lundin, who, in due time, turned over to the observatory an excellent piece of optical work.

The objective was received in Flagstaff early in 1929, and was soon placed in its mounting. This mounting had meanwhile been under construction in the observatory shop in the able hands of Mr. Stanley Sykes, the observatory instrument-maker. The performance of the lens exceeded our expectations and we have been led to regard it as possibly the best search-instrument in the world to-day.

This instrument and its dome are fully equipped with electric conveniences, and it is much the most satisfactory to operate of any of the observatory's telescopes. It has a seven-inch aperture guide telescope, provided with a very sturdy diagonal prismatic eyepiece which makes for efficiency and comfort in observing.

The electric switches for operating the dome and the slow motion of the driving clock are conveniently placed for the observer at the guiding eyepiece. The setting circles are large, and arranged to make the accurate pointing of the instrument easy and quick. The driving clock is large and of excellent performance, and, as the worm wheel is exceptionally large and of highest quality, accurate guiding of the instrument is easy to attain.

The objective is of the Cooke three element "Astro" type, and has a focal length of 66.5 inches. It covers an unusually large plate—14 x 17 inches. As the definition is good over nearly the full width of the plate, about 150 square degrees of sky are well recorded on each plate. With an hour's exposure—the time commonly given—the plates record from about 50,000 to 500,000, or even more, stars, depending upon whether the region of the sky photographed is one with few or many stars.

On the tube of the main telescope is mounted a smaller camera for check purposes. This is a valuable adjunct, for occasionally on the plates of the main instrument will appear a questionable image, and the observer quickly decides its nature by looking it up on the plate of the check camera. This camera of 5-inches aperture and excellent quality is kindly loaned by Professor W. A. Cogshall, of Kirkwood Observatory, Indiana University. An 8-inch Ross type objective is now under construction to take the place of the lens on loan.

As soon as the large lens was placed in its mounting the preliminary adjustments and tests of the instrument were rushed to completion. And then promptly we began the first plates of the Planet X search series in order to get plates that season of Dr. Lowell's predicted favorable region in Gemini, then dropping rapidly into the evening sky. While the director was making the adjustments and tests of the new instrument, he instructed Mr. Tombaugh —who had recently come to the observatory—in the operation of the instrument, and also in the methods of photography, until he could carry through all the operations alone.

Our previous experience in such work

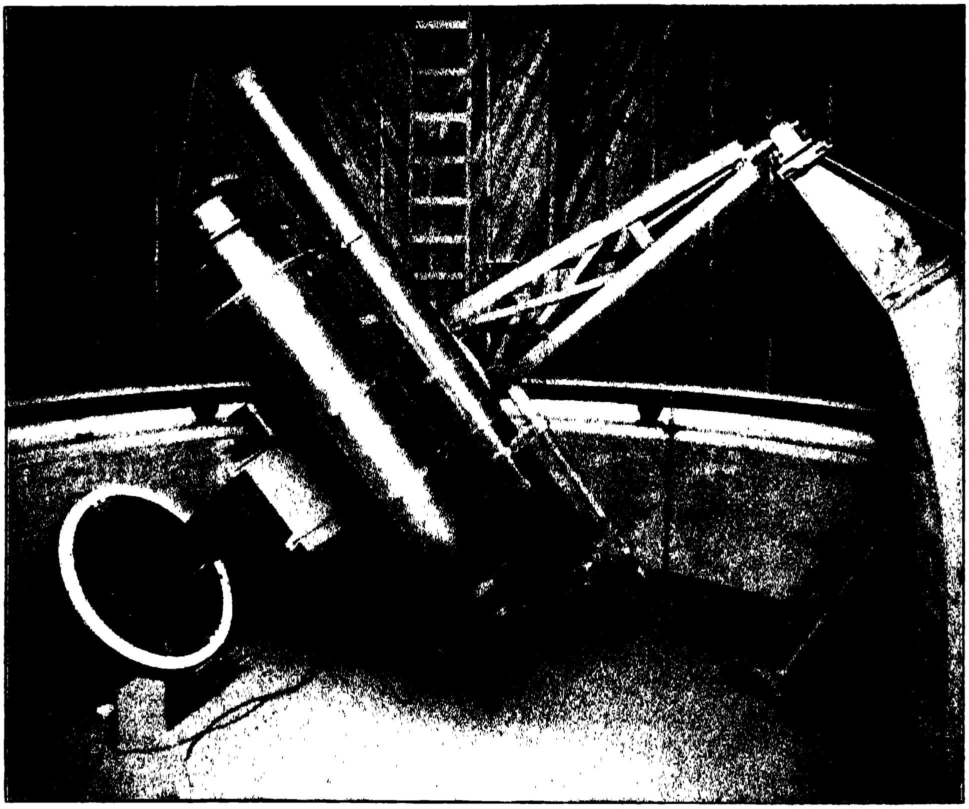


FIG. 4. THE NEW 13-INCH PHOTOGRAPHIC TELESCOPE

FAMOUS FOR HAVING BROUGHT TO LIGHT THE NEW PLANET.

impressed upon us the vital need with this new instrument of bringing each plate into exact focus in the telescope. To accomplish this we designed a convenient testing table, enabling the observer to bring the sensitive surface of every plate quickly into precisely the proper focal position, thus eliminating the all too frequent disastrous curvature faults of such large plates (14 x 17 inches). We designed also special plate holders supplied with special bearings for the plates over which thumb screws spring the plates into closest possible adjustment to the focal surface of the large lens. This insures that the focal qualities of all plates will be the same—a matter of the highest importance in the careful comparison of the plates.

It also was necessary to make tests of different photographic plates in order to take advantage of the most suitable available brand for this special work. For ease and accuracy in the examination, it is vital that the plates be exactly matched in the character of their photographic images, a result secured only by following a perfectly systematized procedure of photography as well as very precise instrumental adjustments.

Thus, in March, 1929, the search for the trans-Neptunian planet could at last be resumed, and with a conveniently operated and highly efficient instrument, well equipped with auxiliary apparatus, and with better perfected means and methods than were ever available before. The prospects were promising, for it seemed such an object could not now long escape being detected.

Care was exercised in the choice of guide stars to cover effectively the desired region of the sky when Mr. Tombaugh began carefully to follow out the systematized search program. The work went on for nearly a year, with nothing more than the expected things coming up—numerous asteroids and variable stars—at least nothing very exciting.

Then, on February 18, 1930, when comparing by the Blink method two plates of the region about Delta Geminorum made January 23 and January 29, 1930, he came upon an object that had shifted among the stars, between the two dates, by an amount that on the face of it indicated the body was very distant, and perhaps the object long sought for. Fortunately, a third plate of the region was available, and it, too, showed the object. The reality of these images on the three plates could not be questioned as being the record of a distant, slow-moving, solar system body. But of course they were not in themselves sufficient to decide its nature, and it was necessary to go about securing additional observations and information from every possible view-point in order to decide the important matter.

The first question was, would the next plate show it in its expected place among the stars as estimated from the January positions. It did, and so did the next and the next plates. In short, the object continued to meet expectations. Our early fears were that it would speed up, and turn out to be only an exceptional asteroidal or cometary body.

As soon as possible, we pointed the large refractor upon it with one question uppermost in our minds—will it show a disk? It did not; that was disappointing. But we continued to scrutinize it carefully each night, and to compare it with neighboring stars to judge of its color, of the constancy of its light and to see if, under exceptionally favorable visibility, it might show some indication of a disk. Under the most careful scrutiny, it showed no sign of any cometary features. Mr. Lampland then photographed it with the large reflector to see what such plates might show, and, in particular, to follow its path and to get accurate positions for finding its orbit. The observations continued to find it night after night in its expected place.

Neither the eye observations at the visual telescope nor those with the photographic reflector indicated the slightest variation in its light. It was seen to be brighter visually, compared with some of the near stars of about its brightness, than it was on the photographs, indicating that it was not blue

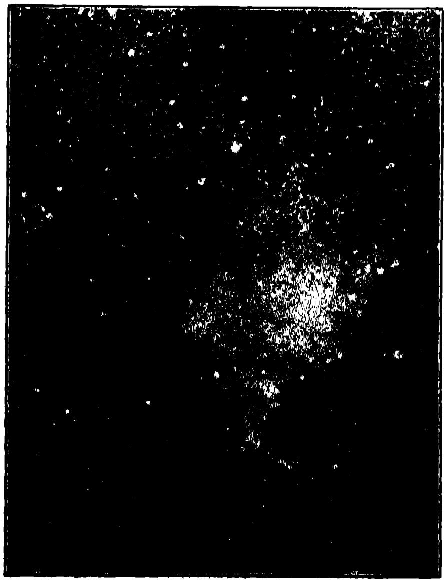


FIG. 5. SMALL SECTION OF A PLATE OF CYGNUS REGION OF SKY

MADE WITH 13-INCH TELESCOPE. IT SHOWS HOW THICK THE STARS ARE IN SOME REGIONS AND THIN IN OTHERS. THE PICTURE SHOWS THE FAMOUS AMERICA NEBULA.

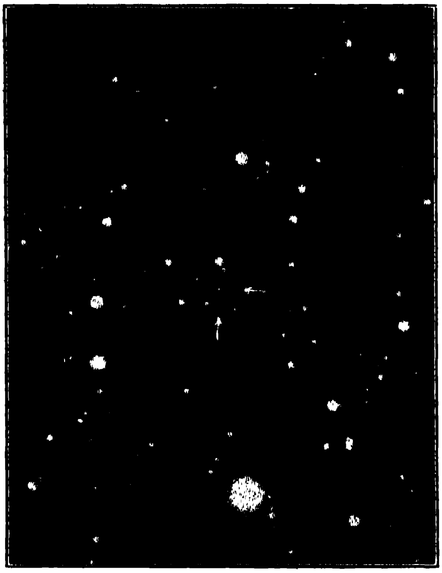


FIG. 6. A SECTION OF ONE OF THE DISCOVERY PLATES

THAT OF JANUARY 23, 1930. THE ARROWS NEAR THE CENTER ARE POINTING TO THE LITTLE IMAGE OF PLUTO.

but yellow. The object is faint for the spectrograph and Mr. Lampland kindly made with the reflector a special pair of plates of it, one with blue light, the other with yellow light; and also a similar pair of the planet Neptune and its nearby stars. These plates agreed with what the eye had seen in the telescope, and indicated the stranger was yellowish, not bluish like Neptune. This color result implied an albedo (surface reflectivity)—like those of the inner planets—and also probably a high density. This was a bit surprising since its neighbors, Neptune and Uranus, are both of bluish color, of high albedo and of low density. Dr. Lowell's estimate of the magnitude was too high, doubtless in part because he naturally was influenced by the very high albedos of Uranus and Neptune.

Meanwhile, it was possible for us to follow it every night and to lay out its expected path empirically, and we were encouraged each succeeding night to find the object just where we estimated it would be. It was keeping a steady course. It was possible after a while to predict within a day or two when it would reach the end of its westward swing (its stationary point) in the sky, and would start moving eastward, reversing its drift among the stars. Its apparent motion was, of course, largely due to our own shifting view-point, caused by the Earth's daily swinging through about one degree of its orbit around the sun. The photograph in Fig. 9 shows its apparent path among the stars as charted by Dr. Lampland from the search plates and those he made at the reflector.

The observed amount of its drift from day to day afforded a measure of its distance from us. Thus, after a few weeks, it showed that its distance was definitely much greater than Neptune's and between 40 and 43 times the distance the earth is from the sun. Its drift rate was the distinguishing test for distance, and from the discovery plates

FIG. 7. MR. C. W. TOMBAUGH

THE CAREFUL-WORKING AND KEEN-EYED YOUNG MAN WHO WAS FIRST TO FIND THE RECORD OF PLUTO ON THE PHOTOGRAPHIC PLATES.

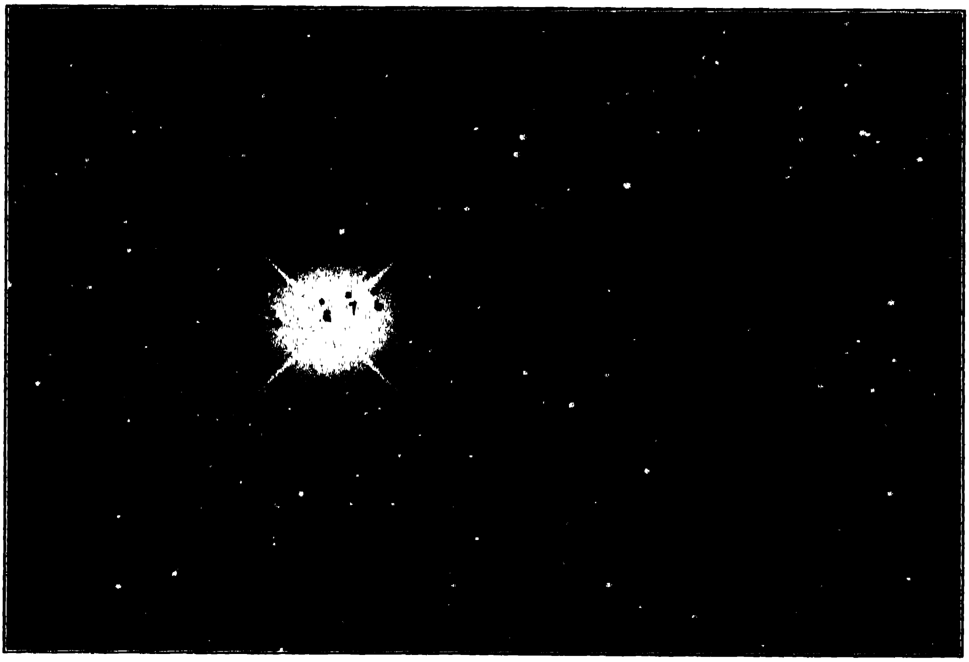


FIG. 8. PLUTO

APPARENT PATH OF THE PLANET AMONG THE STARS, FEBRUARY 19 TO MAY 10. DATE OF PHOTOGRAPH MARCH 4, 1930. THE POSITIONS, EXCEPT THE FIRST FOUR, ARE FROM 42-INCH REFLECTOR PHOTOGRAPHS BY C. O. LAMPLAND. THE BRIGHT STAR IS δ GEMINORUM. SCALE $1^{mm} = 7''.3$ (APPROX.).

on continued to show the object was trans-Neptunian.

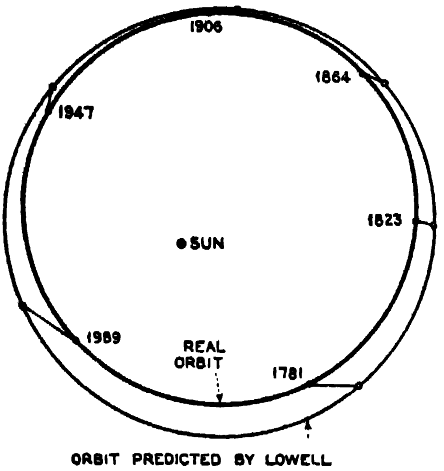
Finally, on the night of March 12, a message was telegraphed to Mr. Putnam, the observatory trustee, to be forwarded to Harvard Observatory for distribution, the next day to observatories and astronomers, which read as follows:

> Systematic search begun years ago supplementing Lowell's investigations for Trans-Neptunian Planet has revealed object which since seven weeks has in rate of motion and path consistently conformed to Trans-Neptunian body at approximate distance he assigned. Fifteenth magnitude. Position March twelve days three hours GMT was seven seconds of time west from Delta Geminorum, agreeing with Lowell's predicted longitude.

The announcement of the finding of Lowell's planet was delayed a few days in order that it might be made on the anniversary of his birth—March 13. It was also made public on that morning at the Arizona Teachers College in the presentation of a scholarship prize given each year in Dr. Percival Lowell's memory by his widow, Mrs. Constance S. Lowell.

It is a coincidence worthy of remark that March 13 is also the anniversary of Sir William Herschel's discovery of the planet Uranus.

In passing, we can only remark upon the tremendous, instant, and persistent demand from the public press for information. We did not feel at that time that we had much ready to give out, and were, besides, too much occupied in following the urgent phases of the work to do more than give a few brief comments. The number of telegrams, cablegrams and letters received at the obser-



—*Courtesy Scientific American*

FIG. 9. THE ACTUAL AND THE PREDICTED ORBITS OF PLUTO

THE REAL POSITIONS OF THE PLANET AT INTERVALS FROM 1781 TO 1989, AND THE POSITIONS RESULTING FROM LOWELL'S CALCULATIONS.

vatory, as well as the large amount of space given the finding of the new planet by the newspapers and magazines, is clear proof of the wide-spread interest in astronomy to-day.

We felt it highly desirable to determine as soon as possible a preliminary orbit for the object, although we fully realized such orbit would be very imperfect in most respects because all the observations then available covered only an exceedingly short section—about 1/1500 part—of the planet's swing around the sun. It seemed that a start should be made, even if some of the orbital elements—its shape and size—could not really be determined, because even an approximate orbit would help show its approximate path for a time in the past and hence assist in indicating where to look for the planet on old plates.[2] For this work, we fortunately had the collaboration of Dr. J. A. Miller, director of the Sproul Observatory, whose experience in orbit work was very valuable in this difficult case. The orbit derived served its purpose, although its eccentricity and period were very much in error, as we feared they would be.

A circular was then issued, giving the preliminary orbit and some further results of the observational work, and stating as a conclusion that this object

> appears to be a trans-Neptunian, non-cometary, non-asteroidal body that fits substantially Lowell's predicated longitude, inclination and distance for his Planet X.

It was also then suggested that the planet be named Pluto, and carry the symbol PL. Many people have asked why we chose the name Pluto. We considered carefully the numerous suggestions offered by many serious minded people. Minerva received a plurality,

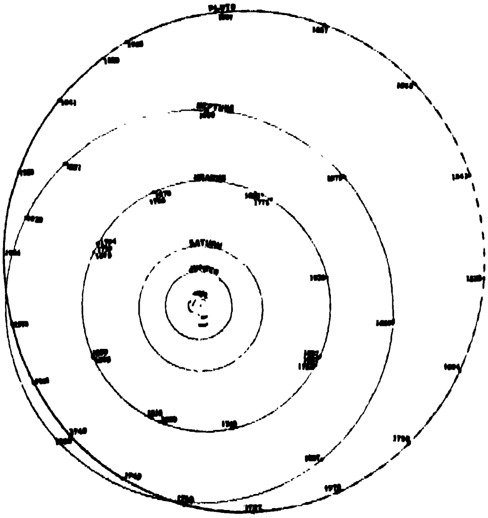


FIG. 10. THE ORBITS OF THE NINE PLANETS TO SCALE AS THEY REVOLVE ABOUT THE SUN

THE POSITIONS OF URANUS, NEPTUNE AND PLUTO FOR THE VARIOUS YEARS ARE AS INDICATED. THE ORBIT OF PLUTO IS CONSIDERABLY INCLINED TO THAT OF NEPTUNE AND HENCE THESE TWO ORBITS DO NOT INTERSECT. DIAGRAM BY C. O. LAMPLAND.

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[2] It was later found on our 1929 plates, the tenth plate with the new instrument having recorded it.

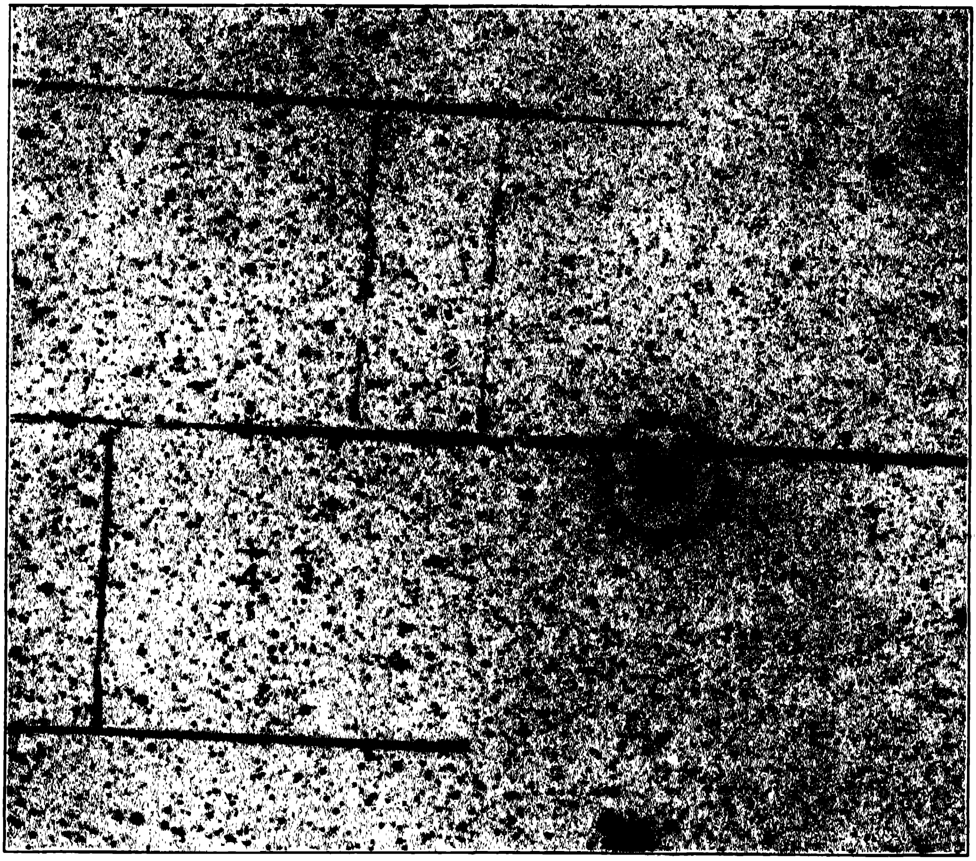

FIG. 11. STAR FIELD AROUND δ GEMINORUM

FROM OLD 5-INCH SEARCH PLATE MADE DECEMBER 18, 1906, BY E. C. SLIPHER. OF SPECIAL INTEREST IS THIS 24-YEAR-OLD PLATE BECAUSE IT SHOWS THE RECTANGULAR EXAMINATION MARKS PLACED THEREON BY DR. LOWELL, ROUND ABOUT WHERE THE PLANET LATER APPEARED ON THE DISCOVERY PLATES. DOTS 1 AND 2, AND 3, AND 4, MARK WHERE PLUTO WAS PHOTOGRAPHED IN 1930 AND 1929, RESPECTIVELY. NO. 1 IS THE DISCOVERY PLACE.

nearly half the letters suggesting this name. We, too, would have liked to use it if it had not been preempted long since by one of the earlier asteroids.

A great many other names were suggested, but the two most popular ones were Cronus and Pluto. Mythologically, there were very good reasons for both. But Pluto is much better known, and his two brothers, Jupiter and Neptune, are already in the heavens. When these three brothers drew lots for the partition of the world, Pluto chose the outer regions. What then could be more appropriate than his now being in these outer regions, and being in the heavens with his two brothers?

The symbols of all the existing planets, except that of Neptune, are so conventionalized and similar that we felt that the proper symbol for Pluto would be the letters "PL" in the form of a monogram which would be easy to write, and to the layman would bring Pluto to mind. The fact that these were Percival Lowell's initials added weight to the thought.

A few astronomers were inclined to

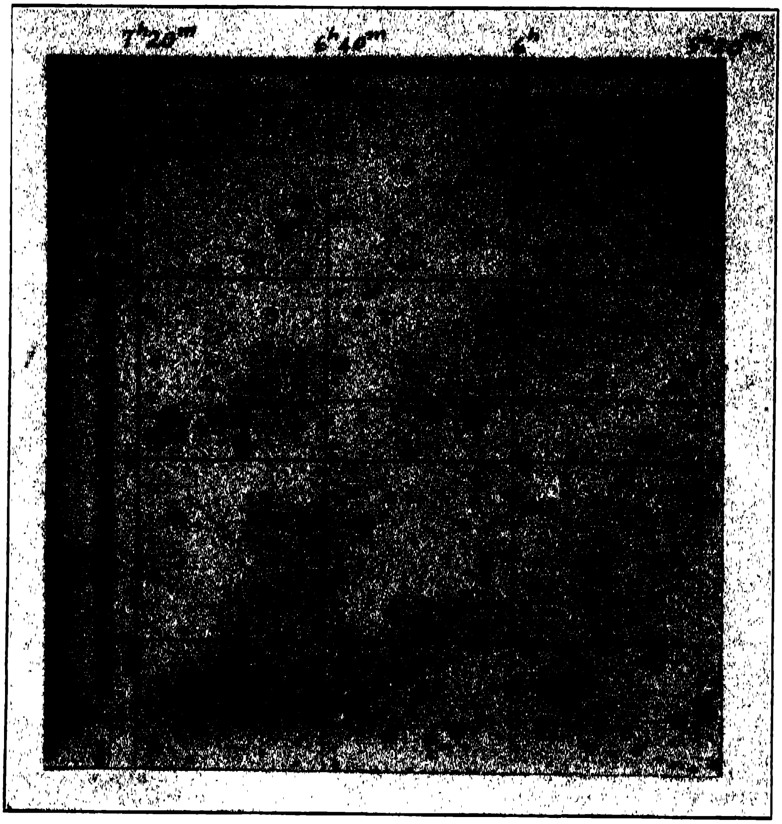

FIG. 12. PHOTOGRAPH FROM A STAR CHART OF THE CONSTELLATIONS GEMINI AND TAURUS

WHICH IS MARKED TO INDICATE ROUGHLY THE POSITIONS PLUTO OCCUPIED IN THE YEARS 1915, 1929, 1930.

question the nature of the object because of the high eccentricity of our first orbit, but this was only temporary. Not long afterwards better orbits were possible because they could be based on much more favorably timed observations and several such orbits were soon forthcoming. These left little doubt as to the nature of the object.

It will now be of interest to see how the recent orbits, determined from the more extended path of the planet and quite reliable, check with what Dr. Lowell had predicted. Dr. A. C. D. Crommelin, of England, whose life work has been largely in the orbit field, wrote on May 20:

> I send circular with the orbit that I deduced for the new planet, assuming that it was photographed at Uccle in 1927. It is in good accord with Lowell's forecast:
>
> | | He (Lowell) gave | My (Crommelin) value |
> |---|---|---|
> | Long. of Perih. .... | 205° | 216 |
> | Perih. passage .. | 1991 | 1884.9 |
> | Period .. .. | 282 yrs. | 265 |
> | Eccentricity . .. . | .202 | .287 |
> | Inclination ... . | 10° | 17 |
>
> It is *very* difficult to think that all these points are pure flukes!
>
> . . . .
>
> It was not till my orbit was in print that I made the comparison with Lowell's prediction, so that there was no *cooking* in arriving at the agreements.

In an article entitled "More About Pluto," Dr. Henry Norris Russell, in

Scientific American, December, 1930, wrote:

> In the second place, the orbit, now that we know it, is found to be so similar to that which Lowell predicted from his calculations 15 years ago that it is quite incredible that the agreement can be due to accident. Setting prediction and fact side by side, we have the following table of characteristics:

	Predicted	Actual
Period	282 yrs.	249.17
Eccentricity	0.202	0.254
Long. of Perihelion	205°	212°30′
Perihelion Passage	1991.2	1989.16
Inclination	about 10°	17°9′
Longitude of node	not predicted	109°22′

> Lowell saw in advance that the perturbations of the latitudes of Uranus and Neptune (from which alone the position of the orbit plane of the unknown planet could be calculated) were too small to give a reliable result, and contented himself with the prophecy that the inclination, like the eccentricity, would be considerable. For the other four independent elements of the orbit, which are those which Lowell actually undertook to determine by his calculations, the agreement is good in all cases, the greatest discrepancy being in the period, which is notoriously difficult to determine by computations of this sort. In view of Lowell's explicit statement that, since the perturbations were small, the resulting elements of the orbit could at best be rather rough approximations, the actual accordance is all that could be demanded by a severe critic.
>
> Even so, the table does not tell the whole story. The diagram Plate on page [Fig. 9, p. 16] shows the actual and the predicted orbits, the real positions of the planet at intervals from 1781 to 1989, and the positions resulting from Lowell's calculations.

In brief, Pluto's credentials as a member of the Sun's family of planets are of high standing and have been fully approved, and he stands the ninth in discovery and in order of distance from the Sun.

It was early realized that the faintness of Pluto would, in itself, make the detection of a disk much more difficult than if it were brighter. Tests of a specially designed target of various illuminated graduated apertures set up about a mile away, and observed through the large telescope, counterparting the observations of the new planet and with the same telescope, confirmed indications of theory. These observations, carried out mainly by E. C. Slipher, experienced in the observation of small satellite disks, and checked by one of us, indicated that Pluto could have a disk of nearly 5/10 of a second of arc and not be detected by our best observations. However with most favorable—much brighter—lighting of such an object about half this size of disk would be detectable. Now our Earth, if seen at the distance of Pluto, would have a disk of only 43/100 of a second of arc, and under faint lighting would probably not be seen to show a disk. Certainly no disk could be seen if its albedo were as low as that of Mercury or the moon. Or, in other words, these experiments indicate that Pluto owing to its faintness could have a diameter as large as or a little larger than the earth and its disk not be recognizable under our best observing conditions.

Hence it is possible that Pluto may be at the most about 10,000 miles in diameter, of a very low reflectivity comparable with that of Mercury, and have a density possibly equal to that of the Earth. Such a planetary body would fit the observations to date without serious conflict. If, sometime, a satellite should be discovered for Pluto, we could readily get his mass accurately.[3]

The color of Pluto indicates for him a very different atmosphere from that which envelops Neptune; and, for all we can tell, Pluto, like Mercury, may be destitute of atmosphere. Of all the planets, these two obviously have the greatest extremes in the intensity of

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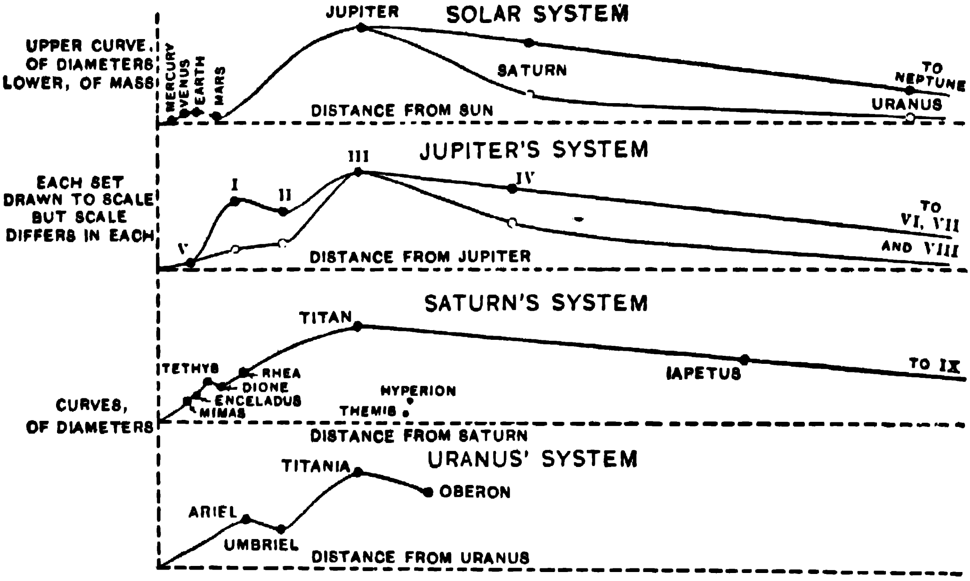
[3] Since this was written, Nicholson and Mayall have published their work on the probable mass of Pluto, indicating a mass approaching to the Earth's.



MASSES OF PLANETS AND SATELLITES.

—*Courtesy Macmillan Co.*

FIG. 13. DIAGRAM

SHOWING THE SIZE AND DISTANCE RESEMBLANCES BETWEEN THE SUN AND ITS PLANETS AND THE GIANT PLANETS AND THEIR OWN FAMILIES OF SATELLITES.

sunlight they receive. Because of its great distance, the sunlight that the new planet receives has only about 1/1700 the intensity of that which the earth enjoys. Hence this very remote planet is so little warmed by the Sun that it has, no doubt, a very low temperature. To one on Pluto our Sun would not show any disk but only a bright star point, to the unaided eye.

Owing to the considerable eccentricity of his orbit the light and heat Pluto receives from the sun will differ greatly depending on where he is in his orbit. This means that his brightness also will vary considerably for us. He is now growing slowly brighter because he is nearing the sun and us. He will continue to brighten until the year 1989, after which time he will begin to grow fainter for the following 125 years during which time he will be receding from the sun as he swings out into the most distant portion of his great orbit.

At present, we know nothing of the length of Pluto's day, and our only hope of learning anything of his diurnal rotation is by his showing a measurable periodic variation in light—a not too remote prospect. Pluto's year, as was noted a bit ago, is about 250 of our years, and is already fairly accurately determined. Hence he goes slowly around the Sun, trailing at a greater distance his more speedy brothers. It is interesting to note that his year is almost exactly 3 times as long as that of Uranus and quite closely 1½ times that of Neptune.

It will now be of interest to consider for a moment the arrangement of the members of our solar system.

Fig. 13 is from Dr. Lowell's book, "The Evolution of Worlds." It is interesting here because the addition of the new ninth planet to the solar system makes still more striking the resemblance between the Sun with his family of planets, and that of Jupiter and his family of satellites (seen in the two upper curves). In drawing attention to this matter Lowell concludes: "Method here is unmistakable."

The high inclination of Pluto's orbit, too, fits in with this scheme as the inclination of some of the outer satellites of these families is extreme.

Thus the finding of Pluto is impressive, not merely because it adds another planet, and greatly expands the known domain of the Sun, but also because it hints that, out in this new extension of the Sun's domain, planetary affairs may differ markedly from what we might have supposed, influenced by our acquaintance with the previously known planets.

The fruitful issue of his courageous exploration of the solar system beyond Neptune is a fitting and lasting tribute to the genius of Dr. Percival Lowell, for two decades the outstanding worker in planetary investigations. He pursued his research problems with rare insight and an enthusiasm that would not yield to unfavorable criticism. And he provided for his observatory's continuance after he would be gone. It is especially lamentable that he could not live to see the confirmation that has come to many of his conclusions and now crowned by the finding of his trans-Neptunian planet. This is at the same time no small reward for the long years of persevering work of the observatory staff always doing their utmost to bring to successful completion the observatory program inspired and sustained by his earlier leadership.

THE NATURE OF METALS IN RELATION TO THEIR PROPERTIES

By **EARLE E. SCHUMACHER**
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INTRODUCTION

THE methods of extracting metals from their ores and fabricating them constituted the art of metallurgy in the older sense, an art whose development has closely paralleled the rise of civilization. The modern science of metallurgy, on the other hand, concerns itself to a large extent with the explanation as to why metals behave as they do and in particular why the methods employed in the art produce the effects they do. This science, as distinct from the art, is of comparatively recent origin. It is, indeed, only since the development of the tools used in modern research, notably the microscope and x-ray, that important steps have been made toward the analysis of metallic structure. Rapid progress has been made in the last twenty years and to-day there is available a vast fund of information in regard to the nature of metals in relation to their properties.

Two of the most important properties of a metal are its hardness and strength. These properties are closely related and in general the magnitude of one indicates the magnitude of the other. The development of the relationship between the nature of a metal and the hardness and strength constitutes one of the most interesting chapters in the science of modern metallurgy.

THE NATURE OF METALS AND THE MEANING OF HARDNESS

Metals, in general, are solids at room temperature. Most solids are composed of a number of irregularly shaped crystals pressing closely against each other. This is schematically represented in Fig. 1, which shows a cross-section through such an aggregate. X-ray studies have shown that the crystal itself is composed of minute building blocks or atoms, which are arranged in a regular geometrical pattern called the space lattice. The dimensions and shape of this lattice are different for the different metals. Most common metals, however, have a face-centered cubic lattice, a unit of which is shown in Fig. 2a. The position of the atoms in the lattice determines certain planes which extend throughout each individual crystal. Two sets of these planes are illustrated in Figs. 2b and 2c. In 2b the planes are shown parallel to a cube face; in 2c the planes are drawn through the cube edges. It is fairly obvious that sliding may take place easily between these planes, since there are no atoms to interfere with the relative motion of the two sections. Actually, sliding or slip, as it is generally termed, occurs more readily along one plane than another due to the difference in spacing between planes and the concentration of the atoms on adjacent planes.

From this brief description of the nature of the lattice it is apparent that the hardness or the strength of a single crystal of a metal depends upon the resistance to an applied force encountered when the various planes of atoms slide over one another. This sliding of the atomic planes constitutes the mechanism involved in permanent or plastic deformation. Sections of the crystal slide over one another but each section moves intact. This is illustrated in Fig. 3 which shows the slip bands developed on a polished surface of lead by plastic deformation. The projection of the sections which have slipped above the polished surface of the specimen has given rise to the series of parallel lines visible in each crystal face. The same action is illustrated in Fig. 3a which is a schematic representation of the progress of slip when a single crystal is deformed in tension.

The Causes of Hardness

The term hardness is commonly used in a rather vague and general sense, but the principle properly associated with the term, at least when referred to metals, is the ability to resist plastic deformation. Since deformation is the result of the sliding of crystal sections on slip planes, any alteration in the metal aggregate which interferes with slip will cause an increase in hardness. Some metallurgical processes which produce useful hardness in metallic materials are: (1) alloying of two metals to form a solid solution, (2) cold work, and (3) heat treatment.

The alloying of two metals to form a solid solution results in a crystal lattice containing both kinds of atoms. The lattice of the solvent persists, but the differences in potential fields surrounding the two types of atoms have very important effects. There is probably not only a general tightening of atomic bonds but also some distortion of the slip planes caused by displacement of atoms from their regular positions. Either of these effects may be sufficiently great to increase resistance to slip. The conception of lattice distortion is illustrated in Fig. 4. The figure in the upper left illustrates schematically a cross-section through a metal consisting of one

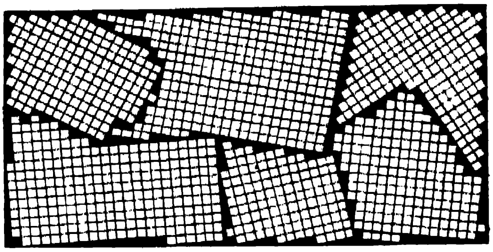


FIG. 1. SCHEMATIC REPRESENTATION OF METALLIC GRAINS.

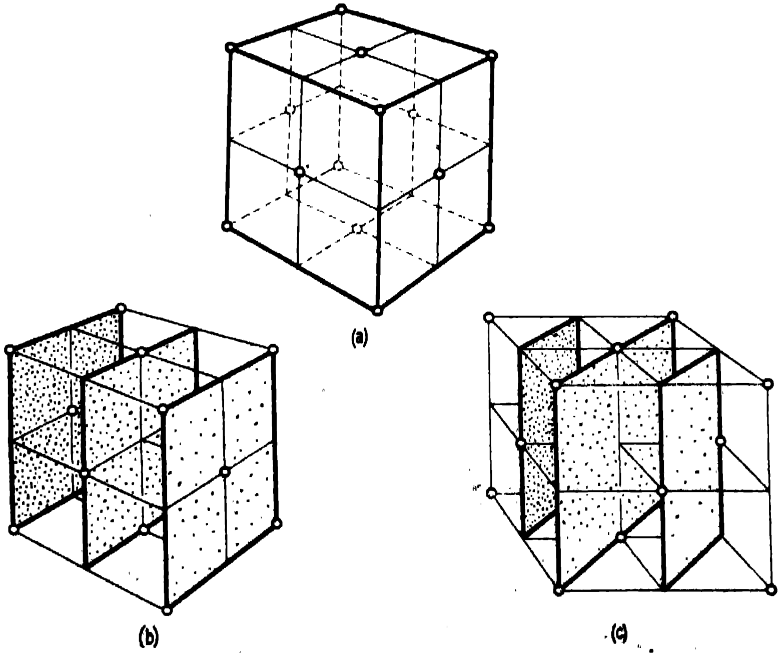


FIG. 2. TWO SYSTEMS OF PARALLEL PLANES THROUGH A CUBICAL ARRANGEMENT OF ATOMS.

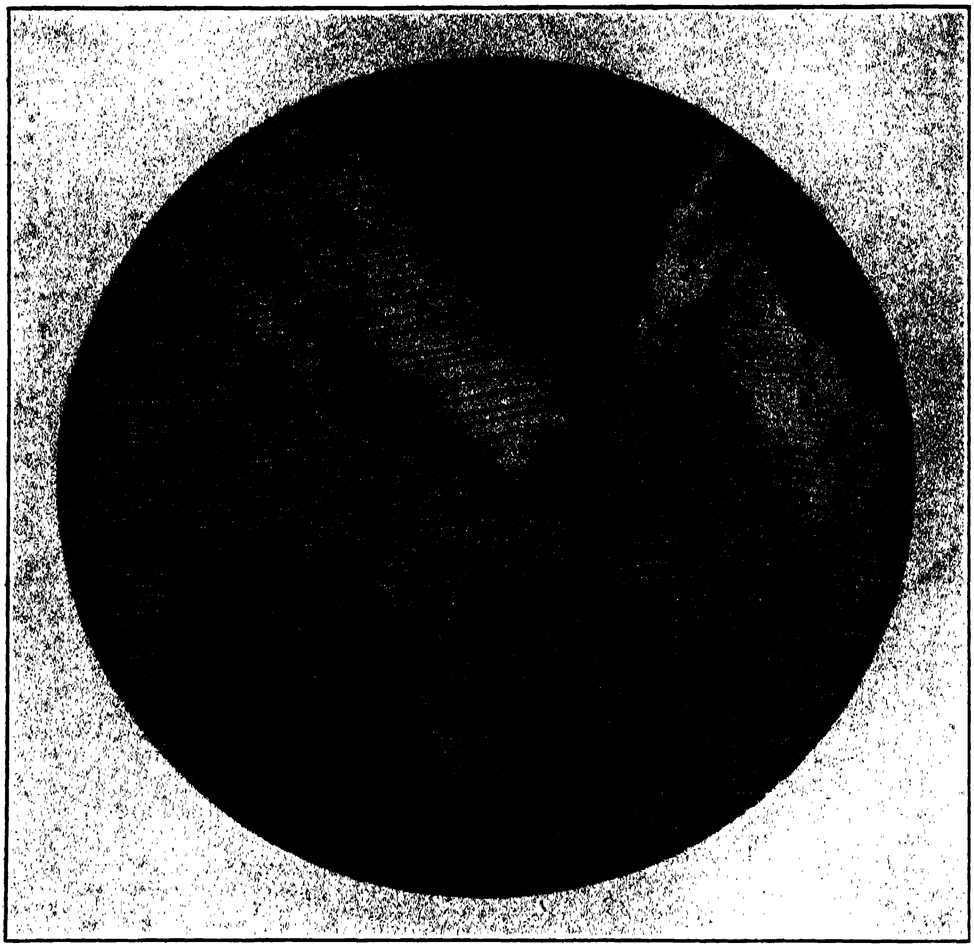


FIG. 3. PHOTOMICROGRAPH OF STRAINED LEAD
SHOWING SLIP BANDS AND TWINS. ORIGINAL MAGNIFICATION 150 ×.

kind of atom. The figure in the upper right shows the local distortion caused by a single foreign atom in solid solution.

Cold work, where hardness is caused by bending, rolling, hammering, drawing, or otherwise deforming the metal when cold, is one of the most important methods of hardening and strengthening metals. Some familiar materials which are hardened in this way are hard-drawn copper, spring brass and bronze, and cold-rolled steel. The mechanism of hardening by cold work seems very complex. Worked metals show a general breaking up of large crystals into small fragments. There is also considerable elongation of the individual crystals in the direction of working. X-ray studies reveal that the planes of atoms undergo a change of orientation during working and that the lattice is severely strained. This indicates that the hardening due to cold work may be caused by at least two factors; lattice distortion, such as occurs in solid solution hardening, and disregistry of slip planes from fragment to fragment.

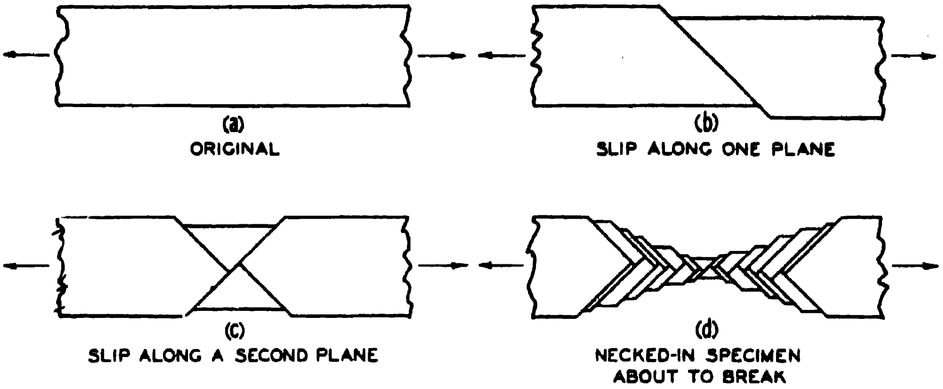


FIG. 3A. SCHEMATIC REPRESENTATION OF PLASTIC DEFORMATION (BY TENSION) OF A METAL BAR COMPOSED OF A SINGLE CRYSTAL.

The third type of hardening, hardening by heat treatment, depends upon the presence in the metal of two or more phases (homogeneous parts), the relative quantities of which depend upon the temperature of the metal. To produce an increase in hardness in the metal, the heat treatment and subsequent operations must increase the amount of that phase which stiffens the lattice. The stiffening is probably caused by precipitated particles of the second phase keying slip planes. This subject of keying is discussed in more detail later. The nature of the heat treatment differs with different systems. In some cases a single quench from a high temperature suffices to produce an extremely hard material. Carbon steel is such an alloy. Another method of hardening certain alloys consists of a double heat treatment. In this treatment the alloy is heated at a high temperature and quenched. This treatment is followed by an aging at a lower temperature. Commercial alloys which are hardened by this method are duralumin, tempalloy, lead-calcium and lead-antimony. A study of this latter type of hardening has resulted in extremely interesting developments in connection with the nature of metals. Because of this, a brief historical account of the evolution of this method, together with

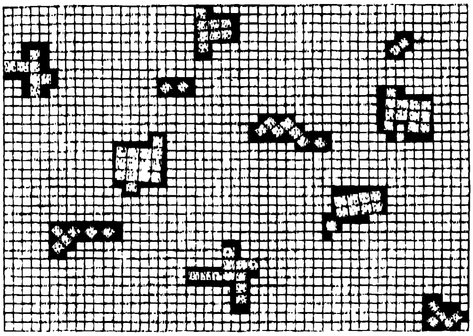
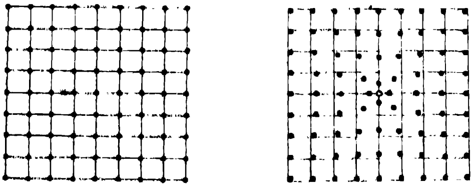
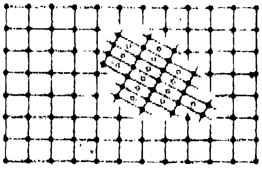


FIG. 5. SCHEMATIC REPRESENTATION OF THE KEYING OF SLIP PLANES BY PRECIPITATED PARTICLES.



SPACING OF ATOMS ON A CUBIC LATTICE

DISTORTION OF A LATTICE BY A STRANGER ATOM



COMPLETE PRECIPITATION OF A SECOND PHASE FROM SOLID SOLUTION THE PRECIPITATE IS A METALLIC COMPOUND A CRYSTAL CONTAINING SEVERAL MOLECULES IS SHOWN

FIG. 4. LATTICE DISTORTION

a fairly detailed discussion of one plausible age hardening theory seems in place.

AGE HARDENING OF METALS

Age hardening was discovered in 1911 by Dr. Alfred Wilm while experimenting with aluminum alloys. It was not until 1919, however, that Dr. P. D. Merica and his associates discovered the fundamental condition necessary for this type of hardening to occur, which is that there must be present a constituent in the alloy whose solubility in the solid state decreases with decreasing temperature. When the alloy is held at a high temperature, this constituent dissolves. Upon cooling quickly, the constituent remains dissolved, but the solid solution is supersaturated. The alloy is now only a little harder than the original solvent. During subsequent aging at a lower temperature, the supersaturated solution breaks down, the excess solute precipitates in small particles evenly distributed, and the alloy hardens.

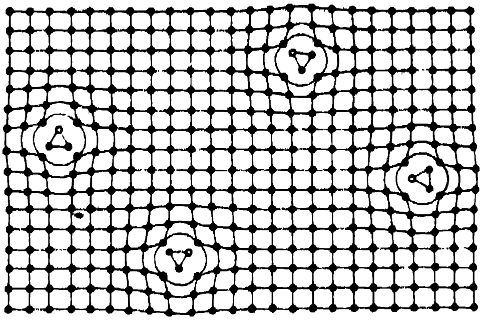


FIG. 6. LATTICE DISTORTION CAUSED BY PRECIPITATED PARTICLES.

In 1921, an explanation of the hardening action was proposed by Jeffries and Archer. They suggested that the precipitated particles act as keys locking adjacent planes of atoms together so as to interfere with relative motion or slip. This explanation has become widely known as the "Action as Keys" theory of the mechanism of age-hardening. Figs. 4 (bottom diagram) and 5 indicate how slip planes are keyed by precipitated particles.

Since the "Action as Keys" theory was first proposed, a number of modifications have been suggested. It has, for instance, been proposed that the precipi-

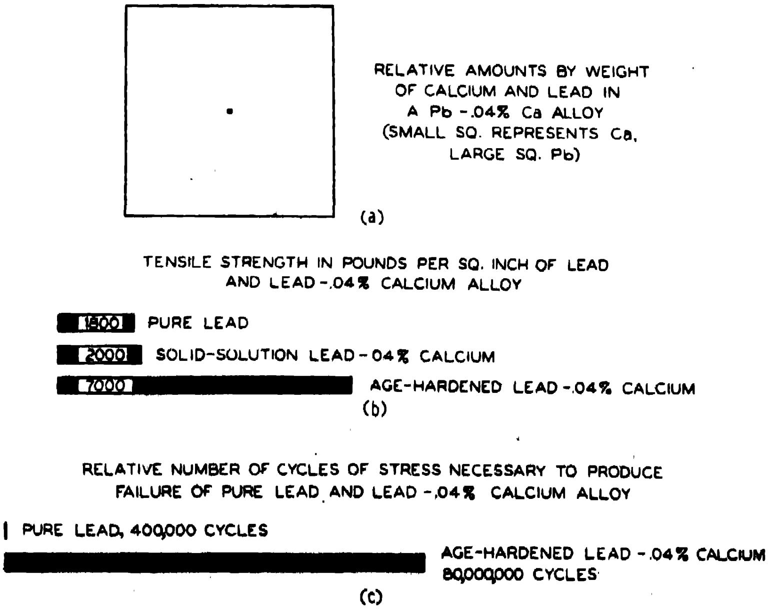


FIG. 7. RELATIVE AMOUNTS OF CALCIUM AND LEAD

tation of the solute introduces strain in the lattice and so distorts the atom planes, thus retarding slip. This mechanism is shown schematically in Fig. 6. It is evident that this theory does not differ from the solid solution theory of hardening except that the distorting effects may be greater and consequently higher hardness values may be obtained. According to these theories it seems entirely justifiable to say that the mechanism of age-hardening depends upon slip interference and it is quite probable that both mechanical keying and distortion keying contribute toward the hardening attained. Under certain conditions and in certain systems mechanical obstruction may predominate; under other conditions and in other systems distortion keying may be the important factor. For instance, in the early stages of precipitation before agglomeration has had time to progress appreciably, it is probable that distortion hardening predominates. In the later stages, after the precipitated particles have agglomerated, mechanical obstruction is probably the major factor in producing hardness. A schematic representation of a precipitated phase that is causing practically no distortion of the solvent lattice is given in the bottom diagram of Fig. 4.

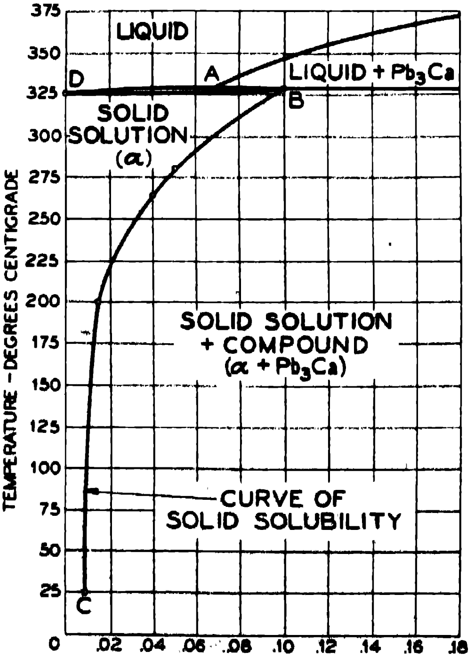


FIG. 9. PARTIAL EQUILIBRIUM DIAGRAM OF THE SYSTEM LEAD–CALCIUM.

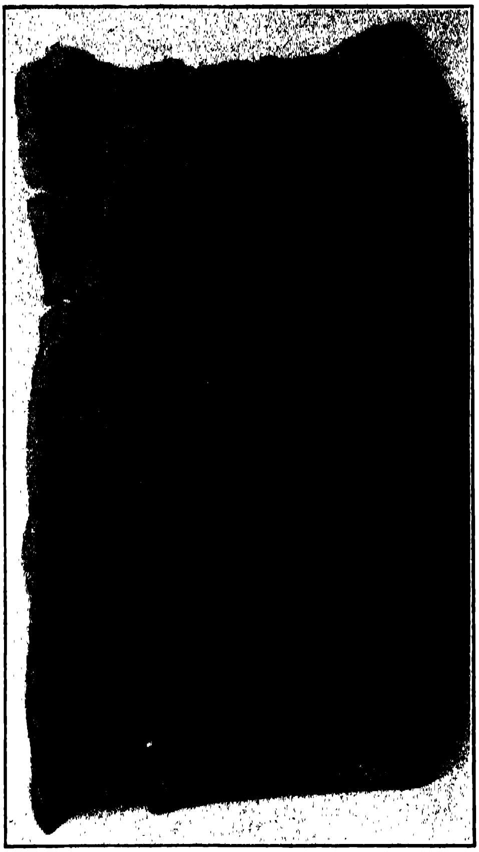


FIG. 8. MACROGRAPH OF A PURE LEAD SHEATH WHICH FAILED IN SERVICE DUE TO INTERCRYSTALINE FRACTURES.

A TYPICAL AGE-HARDENING ALLOY

Of the many dispersion hardening systems which have been reported to date, the alloys of lead and calcium are interesting because of the exceedingly minute quantity of calcium which suffices to produce the age-hardening phenomenon. Fig. 7a represents graphically the proportions of calcium in a lead – .04 per cent. calcium alloy. Fig. 7b shows the tensile strengths of pure lead, solid-solution lead – .04 per cent. calcium alloy, and age-hardened lead – .04 per cent. calcium alloy. From this figure, it is evident that solid-solution lead – .04 per cent. calcium is only slightly stronger than pure lead, whereas the age-hardened alloy has a tensile strength nearly four times that of pure lead. According to theory, finely dispersed particles of a lead-calcium compound, Pb_3Ca, precipitate from the solid-solution lead – .04 per cent. calcium alloy when the latter is aged at room temperature, and the great increase in tensile strength is brought about by these particles keying and/or distorting slip planes.

In Fig. 7c is shown the great increase in fatigue resistance (ability to withstand repeated cycles of stress without fracture) of the age-hardened lead-calcium alloy over that of pure lead. For some kinds of use, such for example as in the sheath of aerial telephone cable, which is exposed to repeated stresses and vibrations, it is expected that the high fatigue endurance of lead-calcium will prove to be valuable.

The aerial telephone cables in this country compose a very costly network of wires protected by many thousands of miles of lead alloy sheath. The stresses and vibrations to which these sheaths are exposed include not only those brought about during installation, but also, and probably more important, those occurring later due to expansion and contraction caused by daily and seasonal temperature changes, and vibrations caused by wind and by the movement of heavy vehicles and trains. On account of the bends which occur in cables at the points of support on the poles, thus localizing the strains, sheath failure is most likely to occur at these points. Since the insulation of the wires in these cables consists of coverings of dry paper, it is evidently important to avoid even small openings in the sheath which might admit moisture. Pure lead as a sheathing material for aerial telephone cable is unsatisfactory, as its service life, probably because of its relatively low

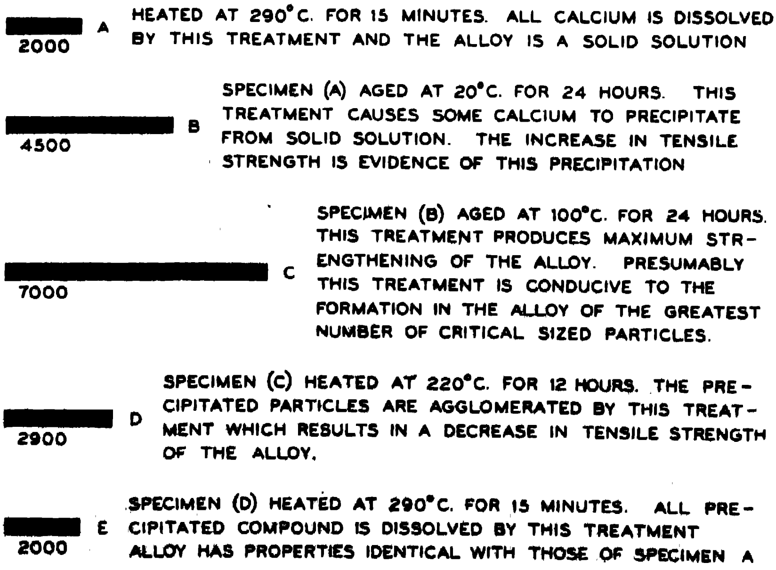


FIG. 10. TENSILE STRENGTH IN POUNDS PER SQUARE INCH OF LEAD—.04 PER CENT. CALCIUM ALLOY IN DIFFERENT HEAT-TREATED CONDITIONS.

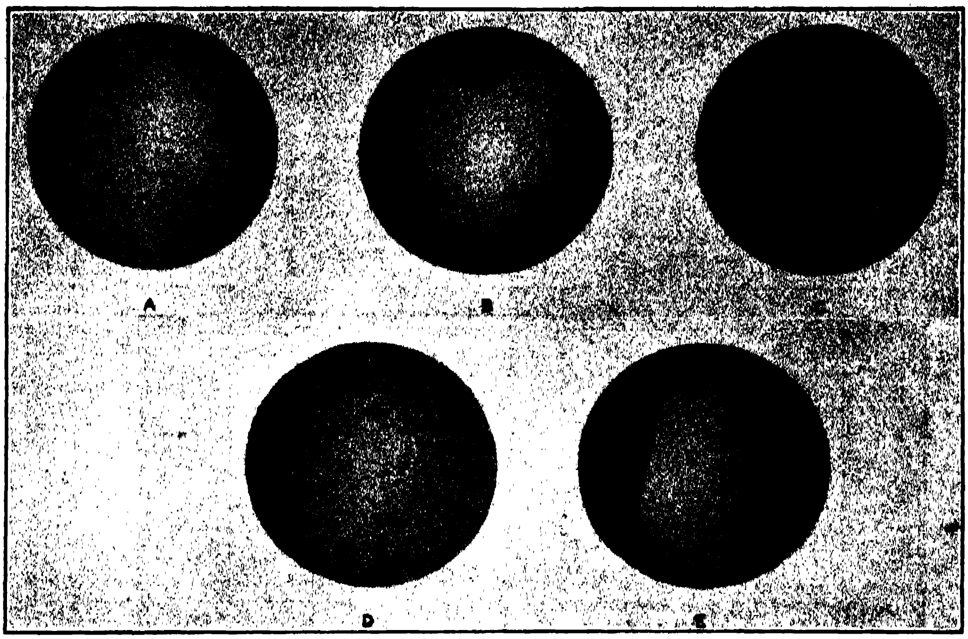


FIG. 11. PHOTOMICROGRAPHS OF LEAD—.04 PER CENT. CALCIUM ALLOY IN THE DIFFERENT HEAT-TREATED CONDITIONS DESCRIBED IN FIG. 10 (ORIGINAL MAGNIFICATION 500 ×)

(A) Specimen heated at 290° C. for 15 minutes. Solid solution structure.

(B) Specimen heated at 290° C. for 15 minutes, then aged at 20° C. for 24 hours. Precipitated phase is submicroscopic in size.

(C) Specimen heated at 290° C. for 15 minutes. Aged at 20° C. for 24 hours and then at 100° C. for another 24 hours. Most precipitated material is still submicroscopic in size.

(D) Specimen "C" aged at 220° C. for 12 hours. The new phase, appearing as small black particles, is agglomerated lead-calcium Pb_3 Ca.

(E) Specimen "D" aged at 290° C. for 15 minutes. All the second phase is dissolved. Structure is again the same as "A".

fatigue endurance, is greatly inferior to that of several lead alloys. A photograph, Fig. 8, somewhat enlarged, of a piece of pure lead cable sheath which failed in service is interesting as an illustration. A network of cracks can be seen extending over large areas of the surface. This condition is typical of lead specimens that have been vibrated for some time. In the laboratory we are now able to produce a similar type of intercrystalline failure by subjecting test specimens to alternating stress. Ability to do this has greatly facilitated the study of fatigue resistance. The comparison of fatigue resistance of pure lead and the lead – .04 per cent. calcium alloy as shown in Fig. 7c was obtained in the laboratory by subjecting specimens of these materials to repeated cycles of equal deflection, 650 cycles per minute. Under this particular laboratory treatment, pure lead fails at about 400,000 cycles of stress, whereas the lead calcium alloy frequently remains unbroken after as many as 80,000,000 cycles of stress. Taking into account the very different and much more complicated conditions to which the sheath is exposed in service, it is, of course, probable that the service life will not show so great a contrast.

THE LEAD CALCIUM EQUILIBRIUM DIAGRAM

In addition to their practical usefulness, the lead-calcium alloys furnish an excellent subject for illustrating the relationship between age-hardening phenomena and phase change in an alloy. Fig. 9 is a constitutional diagram which shows the temperature at which alloys in the composition range covered undergo phase changes. In this diagram the weight percentage of calcium is plotted against the temperature. The total area of the diagram is divided by curved lines into several areas each of which represents a metallurgically distinct phase. The curved boundary lines are of course experimentally determined by various means which we need not discuss here. Each of these bounded areas represents the range of temperature and composition throughout which the number of components remains constant. For example in the entire area to the right of and below the line BC, the material is found to be a solid solution of calcium in lead in which are interspersed distinct particles of a different substance, namely the compound Pb_3Ca. The nature of the components which characterize each of the other areas is similarly indicated on the diagram.

It can be seen that a lead – .04 per cent. calcium alloy is a homogeneous solid solution in the temperature range from 265° to 327° C. Below 265° C. the compound Pb_3Ca begins to precipitate. The hardening produced is dependent on the amount, distribution and particle size of the precipitate. It has long been recognized that maximum hardening is produced by a definite set of aging conditions which presumably produces the greatest number of critical sized particles. Fig. 10 shows how the tensile strength of a lead – .04 per cent. calcium alloy can be varied at will by heat treatment. The structure of this alloy when subjected to each of the treatments described in Fig. 10 is revealed in the correspondingly lettered photomicrographs of Fig. 11.

STRUCTURAL ELEMENTS

In this paper a brief account has been given of some of the theories proposed in the effort to account for the hardening and strengthening of metals. If we could give an explanation of these processes more adequately we could perhaps devise new ways of treating metals which would give even better physical properties. For this reason, and to fulfil the more disinterested aims of pure science, such a more adequate explanation is greatly to be desired and it is, in many places, being sought.

From the discussion given here, it is perhaps hard to see why such an explanation is so difficult to find. One important reason is that metals consist in general of crystalline aggregates, the individual crystals being, usually, oriented largely at random. Hence the considerations advanced above, as to the character of the structure and physical properties of the individual crystal, must be applied to the more complex system of crystal aggregates before the full story of the metal's behavior can be told. For instance, in this larger analysis, account must be taken of the nature of the resistance to deformation at the crystal boundaries, which under some conditions, at least, have considerable effect on the behavior of the metal as a whole. Another reason is that the atoms, which we have regarded as the ultimate components of metals, are themselves highly complex structures, possessing many properties not clearly defined or understood. Until we know more about the properties of the structural elements, the atoms, it is evident that we can not understand as completely as we wish, the behavior of metals.

SOME LESS WELL-KNOWN LEAD PIGMENTS

By Dr. A. H. SABIN
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WHITE lead is the best known and one of the oldest pigments, and so much has been written about it that the method of manufacture and its uses are commonly understood. The same is true, although less publicity has been given to it, of red lead, which has been made for two thousand years. There are one or two other lead pigments less well known, though in use for a long time, which are of interest. White and red lead are always made from pure refined metallic lead, but the natural ore can be treated so as to make paint material.

The greater part of lead ore is the mineral called galena, in which one chemical unit of lead is united to one chemical unit of sulphur, a dark-blue heavy mineral almost always showing crystalline structure. It is often found mixed with pyrites, minerals which contain iron or copper, or both, also combined with sulphur and very commonly with some zinc ore. Where silver is also present it is almost always in the galena, and in smelting it comes out in solution in the metallic lead from which it is recovered by a later treatment. Some lead ore is free, or nearly so, from silver, though sometimes there is so much that the deposit is called a silver mine rather than a lead mine. Because of these different ingredients in the rocks which the miner takes out of the ground, different processes have to be used in separating them, and when the lead ore is very pure, as it is in some regions, the metal can be obtained easily.

It has been known for many years that in a furnace of suitable design galena may be mixed with certain other common minerals to form a flux or melted slag which will carry off impurities. With coke to make a hot fire, the lead and the sulphur which is with it will burn in the hot oxygen of the air that comes through the fire, to make sulphate of lead, the simplest chemical combination of these three elements.

There is just enough sulphur in the galena to convert all the lead, when both are combined with the right amount of oxygen, into lead sulphate. But in the glowing hot furnace this simple process is not the only one that occurs, and some of the sulphur burns directly with the oxygen—both of them are probably white-hot—and goes off as a gas, sulphur dioxide, the same as the gas which forms when pure sulphur burns in the air. This leaves part of the lead to combine, somehow, with more oxygen, for it must be remembered that more air than is theoretically necessary finds its way into and through this intensely hot fire, and the heat is such that the most refractory fire-brick used for furnace-linings does not last very long. It is no wonder that the chemical action is not kept down to just one regular formula. When pure metallic lead and oxygen unite in a more orderly and better regulated manner they form the well-known compound called litharge, where one chemical unit of lead always unites with one chemical unit of oxygen (generally supplied from the air) and this cools to a yellow powder. But in this kind of a furnace this new lead-oxygen material seems to combine, in a way not well understood, with the lead sulphate, which is what we are especially desirous of forming. It does not show any litharge-yellow color nor does it behave like litharge. The result is a white powder, in which, as nearly as we can make out, the greater part is lead sulphate; but a considerable and uncertain part is this annexed lead-and-oxygen unknown compound, which apparently is about as much like litharge as a companionate marriage is like the more definite conjugal union. The analytical chemist, like the census-taker, politely calls it litharge, although he knows it isn't. The more scrupulous theoretical chemist calls it the basic lead ingredient, which is true though not very definite. The proportion of this pseudo-litharge in the "basic lead sulphate" may vary from about a sixth to half of the whole, but the operator tries to keep it rather low, preferably about 15 per cent.

We are now just getting through the furnace part of the operation; obviously this new substance must be cooled and settled out of the great current of furnace-gases and partly burned air before we can do anything with it. In the first place, this great current of hot gas, some of which is air that was not burned, much of it the nitrogen which was the greater part of the burned air, and much of it the burned sulphurous gases, all moving rapidly and carrying a cloud of dust which is the solid matter from burning the lead, passes through a long crooked pipe to let it cool from the cooling effect of the outside world. When it has cooled enough so that it will not set fire to cloth, it is forced by blowers into the lower part, what we might call the basement, of a large and high building. In the floor of the main room are holes every few feet apart each way, through which are short metal tubes or thimbles, to which are tied the bottom of long cloth tubes, perhaps thirty feet long, the upper ends of which are tied and are suspended from an upper floor, so that any powder they may contain may, if they are shaken, fall into the basement. These tubes are perhaps a foot and a half in diameter, they are tied with strings around them near the bottom to the tubes which come up through the floor so that they are bags upside down, and this whole outfit is a bag-house. If you look into the great main room you see nothing but these great rows of bags, near but not touching each other. The cooled gases and floating dust which are blown into the basement, coming from the furnace, enter into all these bags and the gas filters out between the threads of the cloth and is discharged into the outside air, but the dust, which is the basic lead sulphate, stays inside the bags. This is called bag-filtering. At suitable intervals the bags are shaken, either by a mechanical beater or by air pulsation produced by reversals of the blowers, and the white-lead sulphate falls through into the basement, where it accumulates in containers until it is barreled and taken away. As it was carried off from the fire as a fume, floating in the swift current of gas, it will be clear that it must be a very fine powder, suitable to be used as a pigment. One of the companies that makes this calls it sublimed white-lead and has copyrighted this name, but the real white-lead has been made for hundreds of years by a very different process and is a basic carbonate instead of a sulphate, and in many countries it is unlawful to call this sulphate by the name of white-lead. Other people call it basic lead sulphate, which is an accurate name, not calculated to deceive any one. It is a valuable pigment, has considerable durability as a paint material, mixes well with oil and with other pigments, and in paint works well in brushing or spraying. It does not appear to be used alone, but is a common ingredient in mixed or ready-prepared paints as it is highly opaque, is cheaper than the real white-lead, for which it is substituted; if not as durable as that it has permanence enough for many uses, since many people do not expect any paint to last more than two or three

years. For interior work its permanence is ample.

It will be observed that in making the sulphate no attempt is made to obtain any metallic lead from the ore. Separating a metal, as iron or lead, in a pure metallic state, from the ore by any fire-treatment in a furnace is called smelting and for different minerals there are varieties of such furnaces. For very pure lead ores a simple one, of rather small dimensions, easily operated, is used. The ore, galena, is mixed with fuel and put into the furnace, which is known as a Scotch-hearth, and air is blown in at the bottom. The heat of the burning mass decomposes the ore, the metallic lead runs out at the bottom and the sulphurous gas, with the carbonic acid gas which comes from burning the coal, escapes at the open top and is carried off through a hood which may be a vent for a row of these furnaces. In the furnace first spoken of, where the object is to make lead sulphate, the construction and arrangement of the draft and combustion space is quite different, because here the desired product is uncombined metal. But even in the Scotch-hearth part of the metal burns into sulphate, and this goes off up the chimney and with it goes a little more of the lead as sulphide and a smaller portion as sulphite, and these, with a little coal ashes and a very little soot, are carried off in the current of escaping carbonic and sulphurous gas and unburned air. Now, there is enough lead in this floating dust to make it worth saving, so the gases are led, exactly as in the other plant, through a cooling system and into a bag-house and filtered, and the dust thus collected is blue basic lead sulphate, or blue lead, or sublimed blue lead. It is of a dull grayish blue color, which appears to be due chiefly to the blue lead-sulphide in it, not an unpleasant color for some purposes, but too dark to be of value in making house-paints. As a pigment it is sold for painting structural steel, and as the total amount necessarily produced is far more than has ever been sold, some high-pressure salesmanship has been used in trying to sell it. The unsold excess, which is most of it, is accumulated, some greasy rags thrust into the heap and set on fire. It is very bulky and contains much air, and there is enough combustible matter, probably lead sulphide, in it to keep the fire smouldering. It is finally reduced greatly in volume and is of a brownish color, due, no doubt, to oxides. This, which is still a mass which may be shoveled, is put into the basic-lead-sulphate furnace first described and finally comes out as part of its product. It can, if more convenient, be mixed in with the charges of the Scotch-hearth furnace from which it came and part of the lead recovered in this way. Some rubber manufacturers, who use such things in making rubber goods, buy considerable amounts of blue lead, and one large manufacturer sells a great deal to the rubber trade, making no serious effort to sell it as a pigment.

It has some good pigment qualities. It is almost immeasurably fine, which is a rare and excellent thing, it mixes perfectly with oil, and the paint generally (but not always) has good keeping qualities. It is very opaque, and will cover as much surface as any good paint, its color is not objectionable in many places—indeed is liked—and its durability, under favorable use, is perhaps one half to two thirds as much as the average of red-lead paint, which may be considered the standard of all structural-metal paints. It requires more oil to make a serviceable paint than red-lead and while this lessens its durability it makes it cheaper by the gallon. The dry pigment is sold rather more cheaply than dry red-lead, and, other things being equal, cheapness is a good thing. But the labor cost of any painting job is generally at least twice as much as that of paint, and if one paint is better, let us say only a half better, than another, it is more economical to buy, even if the purchasing agent may not think so; in the end he will.

Blue lead, as well as the white basic lead sulphate first described, usually contains some zinc oxide, because the lead ore contains particles of zinc ore, though usually an effort is made to keep this low by selection at the mine or elsewhere. Some lead ores are nearly free from zinc. The blue lead used as a pigment may contain as low as only half a per cent. of zinc oxide, but may be ten times as much, and it has been made from ores rich in zinc to contain 15 per cent. or even more. There is always a little lead sulphite, from 1 to 4 per cent., and the lead sulphide, to which it owes most of its color, usually varies from 8 to 15 per cent. In the basic lead sulphate ingredient of the blue lead pigment, the "basic lead ingredient," which is generally reported as lead oxide, is quite variable, from 18 to 35 per cent., and what is described as lead sulphate is from as high as more than 60 to less than 45 per cent. of the whole.

These wide variations have many causes; the original composition of the ore, which naturally contains zinc, and this zinc is difficult to recover by itself, but as an ingredient of either "blue lead" or the "sublimed white lead" it is accepted by the buyer; then the temperature in the furnace depends partly on the operator; when the air is very damp a great deal more water goes through the furnace than when it is dry, and this affects the kind of chemical action that occurs and the results obtained. In cold windy weather fire burns in a different way than at other times. And above all, the buyer, not knowing what he is getting, accepts variable stuff that he would never take if he were buying definite material like white lead or red lead or zinc oxide, of simple and well-known composition. In using materials of this latter sort there is more of a feeling of certainty.

It has been said that the blue lead sulphate pigment of variable composition is sold as a pigment for use in paint for metal structures. In this use it competes with red lead, a much older and better known material made by all those who produce the by-product blue sulphate, and by many others. It contains from about one half to two thirds as much metallic lead as red lead, and is sold for about two thirds the price. It is made directly from the ore, while red lead is from refined metal. Its sales for paint purposes are probably from 3 to 5 per cent. of the amount of red lead used for paint, perhaps a smaller proportion than that, and while the gross profit on it is more, the cost of selling is much higher. As has been said, the amount sold for all purposes is but a small proportion of its production, so that most of it has to be roasted and reburned into the white sulphate. Part of its ingredients are theoretically unstable, but probably the main popular objection to it is its extreme variability, producing unexpected failures where a previous lot showed favorable results. For other industrial purposes, like the rubber trade, it may be well fitted, because the consumer has a laboratory and finds out in advance exactly how much of each ingredient to put into a batch and thus uses it intelligently.

It is well to say that among people who use metals as such, the term blue lead means pure metallic lead, as distinct from solder, pewter, type-metal or other metals or alloys, and has no connection with pigments. In this sense, again, it is a technical term.

BEYOND THE MILKY WAY[1]

By Sir JAMES H. JEANS, F.R.S.

OUR earth is one of a system of nine planets which, together with millions of smaller bodies, asteroids, comets and meteors, circle round the sun; our sun is one of a system of millions of stars which circle about one another; this star-system is one of millions of star-systems—and here, so far as we know, the sequence ends abruptly. These star-systems are the biggest objects known to science; there is nothing beyond them except the great universe itself. They form the largest subdivision of the universe, and it is from this circumstance that they derive their special importance to science.

The star-system which is best known to us is, of course, our own; we call it the Galactic system, because it is bounded by the Milky Way. We get the best picture which modern science can give us of this system, if we think of it as being shaped like a cart-wheel, with the sun perhaps a third or a half way along one of the spokes, and rotating like a cart-wheel. We still do not know the size of the wheel with any approach to accuracy, but its diameter is probably of the order of two hundred thousand light-years. Still less do we know how many stars there are in the whole wheel. It is almost certainly greater than a hundred thousand million, and may quite well be two, three, four or even five times this number. The band of light we call the Milky Way is formed by the combined light of all the stars at great distances from the sun, including those which form the rim of the wheel. The wheel is held together by the gravitational attractions of the different stars of which it is composed. As a consequence, the outermost stars move most slowly and take the most time to perform a complete revolution, just as in the solar system the outermost planets move most slowly and take longest to describe their orbits round the sun. The sun probably moves round the hub at about 200 miles per second, and takes something over 200 million years to perform a complete revolution.

In the early days of astronomy, this was assumed to be the only system of stars in the sky. Then it began to be conjectured by Kant and Herschel that it was only one of innumerable systems. Recent research has confirmed this conjecture very fully. Something like two million such systems can now be observed; they are the objects we describe as extra-galactic nebulae.

A random collection of extra-galactic nebulae seems at first to show a bewildering variety of size, shape, brightness and constitution, but a scientific study soon reduces them to law and order. It soon transpires that size and brightness go together, and that variations in both originate in differences of distance. The nebula which appears small also appears faint; and does both, merely because it is far away. Thus, the faintness of a nebula gives us a measure of its distance; and we can easily get rid of effects which arise from mere differences of distance.

Also we can avoid all complications caused by the different orientations of the nebulae by a very simple artifice; we reject all those which are not seen edge on, and confine our attention to those that are. We can do this quite recklessly, as some two million nebulae can be seen in all.

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[1] An Evening Discourse given at the Centenary meeting of the British Association for the Advancement of Science, London, September, 1931.

We have now eliminated all the purely geometrical effects arising from differences of distance and of orientation, and are left with real physical differences of shape and constitution. We find that by far the greater number of our edge-on nebulae can be arranged in a single continuous sequence; it is, in brief, a sequence which begins with spheres and ends with flat discs, although other features besides shape change as we move along it. The nebulae at one end of the sequence consist solely of round, fuzzy masses—even the most powerful telescope shows no stars in these. About half way along, stars begin to appear in the outer edges of the nebulae. Then, further along, come nebulae such as the great nebula in Andromeda, which consist of a comparatively small, central, fuzzy mass, surrounded by vast crowds of stars. At the extreme end of the sequence we have pure clouds of stars such as our own system. The comparison of the cart-wheel remains quite a good one, throughout the second half of the sequence, because the nebulae here generally have a thick central projection, which we may describe as the hub of the wheel, while the rest of their structure is flat. In brief, our sequence is one of nebulae arranged in order of flatness, and this suggests a simple theoretical interpretation of the sequence.

We know how increasing the speed of rotation of a body results in a flattening of its shape. The ordinary Watt governor provides an obvious instance—as the engine runs faster, it flattens out. The sun rotating only once every 26 days is an almost perfect sphere. The earth, rotating more rapidly, but still very slowly, is slightly flattened, so that we usually describe it as orange-shaped. Jupiter rotates more rapidly—once every ten hours—and is much flatter in shape. Finally, astronomical bodies which are rotating very rapidly may be almost completely flat. It is natural, then, to try to interpret our sequence of nebulae as one of the bodies which are rotating at different speeds. And as we know that the speed of rotation of a body increases as it shrinks, it seems likely that we may interpret this sequence of nebulae as one of different stages of development or evolution. If this conjecture is sound, a nebula starting with little rotation at first and shrinking in size would gradually increase its speed of rotation as it shrank, *and would move steadily along the sequence as it did so.*

The way to test this conjecture is to calculate for ourselves how a mass of rotating gas would change in shape as it condensed and shrank. Although the mathematical analysis is not simple, and can not be absolutely precise, it is, I think, fairly conclusive; we find that the evolution of a mass of rotating and shrinking gas would be represented exactly by passage along the sequence.

It is not worth enumerating all the detailed changes which, as theory predicts, would accompany this evolution, but one is worthy of attention. The more highly developed nebulae do not show a uniform distribution of gas in their outer fringes, but an uneven distribution which first forms condensations or knots, and finally develops into separate stars, such as we have already seen in the great Andromeda nebula. Mathematical theory not only predicts this, but enables us to calculate the amounts of gas which would go into each of these condensations; in other words, we can calculate theoretically what the masses of the stars ought to be if our theory is sound. It is gratifying to find that these theoretical masses agree pretty well with the masses of actual stars. We may, then, be fairly confident that this is the way the stars come into being; our sequence of nebular configurations is, in effect, a sort of cinematograph film of the birth of the stars.

We may, then, feel on fairly safe ground in tracing the evolution of the universe back from stars to nebulae, but how did the nebulae themselves come into being? The conjecture which at once jumps to the mind is that the nebulae may have been formed by the same process as the stars; just as the stars came into being as condensations in a tenuous uniformly spread gas—the outer fringes of the nebulae—so the nebulae may themselves have previously come into being as condensations in an earlier mass of uniformly spread tenuous gas. This can never be more than a conjecture, but there are strong arguments in its favor, as we shall now see.

We have already seen how differences in size and brightness between nebulae of the same shape are almost entirely due to a distance effect. In other words, the faintness of a nebula gives us a measure of its distance. This makes it possible to estimate the distances of all nebulae even the very faintest, with fair accuracy. The faintest which can be observed photographically in the 100-inch telescope prove to be at the amazing distance of about 140,000,000 light-years. Dr. Hubble finds that the two million nebulae which lie within this distance are fairly uniformly spaced at about 1,800,000 light-years apart. We can construct a model, by taking apples and spacing them at about 10 yards apart, until we have filled a sphere a mile in diameter. This will use about 300 tons of apples. This sphere is the part of space we can see in the 100-inch telescope; each apple is a nebula containing matter enough for the creation of several thousand million stars like our sun; each atom in each apple is as big as Betelgeuse with a diameter equal to, or slightly larger than, that of the earth's orbit.

The circumstance that the nebulae are fairly uniformly distributed through space certainly supports the conjecture that they may have originated out of a primeval gas spread uniformly through space. Moreover, it can be proved that such a gas would not stay uniformly spread through space but would break up into condensations; and that each condensation would have something like the same mass as the observed nebulae. Or to put the same thing in another way, the primeval gas would break up into condensations at distances apart comparable with the 1,800,000 light-years which Dr. Hubble finds for the average distance of the actual nebulae. Thus, although, from the nature of things, we can never know the truth for certain, there are good reasons for conjecturing that the nebulae came into existence as condensations formed by a primeval gas which was spread uniformly, or at least with some approach to uniformity, throughout space.

Cosmogony presents us with a picture of the evolution of the universe—a cinematograph film—in which big bodies continually break into smaller; the film shows the one forever changing into the many. One primeval gas produces millions of nebulae, each nebula produces millions of stars, each star may, perchance, change into a solar system producing millions of planets, comets and meteors. Even this is not the end of the story, for planets may break up and form satellites, satellites may break up and form rings of miniature moons, such as we see encircling Saturn. The extra-galactic nebulae illustrate the first two chapters in this general break-up—I. Primitive chaos into nebulae; II. Nebulae into stars.

The general breaking-up process of which this is the beginning is in operation throughout the universe. It might be thought that the attractive forces of gravitation would continually draw all the broken pieces together again.

The exact reverse appears to be the case. Not only is the substance of the universe forever being broken into smaller pieces, but these pieces forever tend to scatter further and further apart.

To take the example nearest home, the earth is forever driving the moon further away, by the agency known as tidal friction. When we watch the waves of the sea being checked by a sea-beach or a headland, we may reflect that their impact is not only slowing down the earth's rotation and so lengthening the day—it is also lengthening the month by driving the moon further away from the earth. Incidentally, it is also, through the solar tides, driving the earth further from the sun, and so lengthening the year as well.

Again, every ray of sunlight that enters our eye carries mass with it; eight minutes previously this mass was part of the mass of the sun. Every second the sun loses more than four million tons of mass, in the form of sunlight and sunheat. As the result of this continual loss of mass, the sun's gravitational hold on its family of planets forever weakens, and these are driven further off into space. The earth's orbit round the sun is not so much like a circle or ellipse as like a coiled watch-spring—a spiral forever receding into the cold and dark of space.

The same tendency affects the galactic system as a whole. The stars of which it is formed continually scatter their mass broadcast in the form of radiation. As they do so, their gravitational hold on one another weakens, so that the whole galactic system forever expands.

And it must be the same with the other star-systems in space. Throughout the universe, all the smaller broken pieces, satellites, planets, stars, are scattering away from one another in apparent opposition to the laws of gravitation.

Still more surprising and sensational is the recent discovery that the largest pieces of the universe—the great extra-galactic nebulae we have been discussing—are to all appearances engaged in a similar scattering. They, too, appear to be running away from us and from one another. Until recently, it was thought that on the whole the nearer nebulae were approaching the galactic system, while the more remote were receding. We now know that the nearer nebulae appeared to be approaching merely because they happen to lie mostly in the direction towards which the sun is being carried by the rotation of the galaxy; actually we are approaching them. After the sun's motion in the galaxy has been taken into account, all, or nearly all of the nebulae appear to be receding from the galaxy. The nearer nebulae have small speeds, and the more remote nebulae have greater speeds; in general, speed is approximately proportional to distance. This simple law seems to hold to the very furthest of the nebulae—Hubble finds that for every million light-years of distance there is a speed of recession of about 105 miles a second. The last nebula to be investigated at Mount Wilson shows a speed of recession of 12,300 miles a second; its distance, as estimated from its faintness, being about 105 million light-years.

On the face of it, this looks as though the whole universe were uniformly expanding, like the surface of a balloon while it is being inflated, with a speed such that it doubles its size every 1,400 million years.

One of the great puzzles of astronomy at the present moment is whether these apparent motions of recession are real or not. They are deduced from spectroscopic observations; the nebular spectra show displacements to the red, which, interpreted in the most obvious way as Doppler effects, give the speeds already mentioned. Yet every spectroscopist knows that many factors besides motions of recession are capable of reddening light.

There is one strong theoretical argument in favor of regarding the apparent speeds as real. Einstein's original cosmology regarded the universe as being as full of matter as a universe of its size could possibly be without violating the theory of relativity. Recently, Lemaître, of Louvain, has shown that a universe of this type would not be static—there would be an unstable quality about it. The condensation of the primeval gas into distinct nebulae, and the imprisonment of a large part of the free energy of the universe in these nebulae would cause it to start expanding, in which case it would continue to expand, its radius finally increasing exponentially with the time, until it ended up as an empty universe—finite matter spread through infinite space. Throughout the motion, the relative speed of recession of any two nebulae would be exactly proportional to their distance apart, so that, at first glance at least, this theory seems exactly to fit the observed facts. It not only provides a suggestion as to why the nebulae may be receding. It goes much further and predicts that they must be receding; if Einstein's relativity cosmology is sound, the nebulae have no alternative—the properties of the space in which they exist compel them to scatter.

Yet various circumstances suggest a need for caution. For one, the speeds of the nebulae are not strictly proportional to their distances, and it is not easy to explain the discrepancies, which do not look like mere random motions. Again, the very magnitude of the apparent speeds casts doubt on their reality; they would reduce the whole existence of the universe to a mere flash—at any rate in comparison with what we have recently believed. If they are real, Eddington has calculated that the universe must have started from a radius of about 1,200 million light-years, and that its total mass must be about 2.3×10^{55} grams, which is the mass of 1.4×10^{79} protons and an equal number of electrons. So far as we can tell from the masses of the extra-galactic nebulae, the present average density of matter in space appears to be not less than 10^{-30} grams per cc, which, with the same amount of matter, would assign a radius of 13,200 million light-years to the universe—only eleven times its initial value. If, then, the motions are real, the universe is only at the beginning of its career: it can not have doubled many times since it started. And as it appears at present to be doubling in size every 1,400 million years, the few doublings which these figures permit can not have occupied more than 10,000 million years at most.

General calculations on the ages of astronomical bodies point to far longer periods of time than this. The mere act of condensation of the nebulae—the occurrence which seems most likely to have started the expansion—was probably a matter of hundreds of thousands of millions of years. Perhaps there is no real difficulty here; it might well take this long to get the doubling process really going—indeed, Lemaître has calculated that it would take some such time. The real difficulty is that the stars carry intrinsic evidence of having lived through far longer periods than this. Both single stars and binary systems show an approximation to equipartition of energy which must have taken far longer than this for its establishment.

Spectroscopic binaries provide further evidence. These consist of pairs of stars revolving around one another. Observation reveals a complete sequence; it begins with systems which appear to have just broken into two as the result of rotation—pairs of stars describing circular orbits, and almost in contact—and ends with systems in which the two stars are far apart and describing elliptical orbits. Theory suggests that this observational sequence exactly depicts the evolution of a star which has broken into two as the result of excessive rotation. The outstanding importance of this sequence to our present discussion lies in the fact that the stars at the beginning of the sequence are undoubtedly many times more massive than those at the end. It seems likely that those which are now at the end must have begun at the beginning and lost the greater part of their mass in the form of radiation, and to do this would take millions of millions of years. Considerations such as these make it very difficult to believe that the universe can be such an ephemeral concern as the apparent speeds of recession of the nebulae would suggest. There is, I think, every reason to hope that within a very short time we shall know the truth about this puzzle, and, whatever the solution may be, there seems to be a considerable chance that it may provide us with a clue, perhaps even with a key, to the structure of the universe as a whole. Until quite recently, the scientist, like the ordinary man, accepted the fundamental ingredients of our experience—space, time, matter and energy—more or less at their face value. The most obvious and superficial interpretation suggested by every-day experience was assumed to correspond fairly closely to ultimate reality. The theory of relativity has shown that we were utterly wrong about space and time, and we are beginning to suspect that we are still just about as far wrong about matter and energy. The concept of an expanding universe may prove after all to be a false scent, and the truth may lie in some other direction. In either case the observed phenomena must mean something, and their true interpretation, when it is found, may carry us a step on towards the solution of the greatest mysteries of the external world—the nature of space, and of time, matter and energy, and of the combination of all these which constitutes the physical universe.

THE FUNDAMENTALS OF THE RELATIVITY THEORY[1]

By Dr. MAX TALMEY

NEW YORK, N. Y.

INTRODUCTORY REMARK

THE rumor that only a dozen people in the whole world understand the relativity theory is a myth. Competent physicists comprehend the theory and their number is certainly more than twelve. What is true about that rumor is that even highly educated non-physicists know very little of the theory. The reason for this is that its essentials have never been explained in a manner intelligible to a layman. No treatise, scientific or popular, states clearly and saliently the new fundamental ideas, previously unknown, from which the theory was deduced. Educated laymen know that Copernicus discovered the revolution of the planets around the sun; Newton, the mutual attraction of the bodies, etc. But ask a layman what discovery of Einstein's led to his theory and he is at a loss for an answer. It is true, the answer to the question is contained in the better treatises on the theory, but even there it is so entangled in a mass of particulars, uninteresting to the layman, that he is unable to unravel it. To impart to him a fair understanding of the relativity theory the discovery underlying it should be clearly stated right from the start and the encroachments of philosophy and fancy upon it should be avoided throughout. It is a purely physico-mathematical subject and must be treated as such to be comprehensible. The mathematics required in the special relativity theory, which is the foundation of the general one, is quite simple, well intelligible to the average educated laymen. An attempt to explain the theory without touching in the least on mathematics is bound to fail of its purpose.

DISCOVERY UNDERLYING THE RELATIVITY THEORY, RELATIVITY OF SIMULTANEITY

Einstein discovered the relativeness of the simultaneity of distant events. To appreciate this discovery, which forms the origin of the relativity theory, we have to know what is meant by the simultaneity of distant events. Two events that are far apart in space are simultaneous or non-simultaneous according to whether an observer stationed in the middle of the distance between them perceives them at the same instant or at different instants. This definition of simultaneity takes for granted that light travels equally fast in all directions. Since the observer is equally distant from the two events, the light coming from one of them needs as much time to reach him as that coming from the other.

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[1] When I was studying medicine in Munich good fortune brought me in contact with Albert Einstein, then ten years old. For five years I associated with him intimately and frequently. Thus I had the opportunity for observing at close range the extraordinary mentality which Albert manifested already at that young age. I even played a part in its unfolding during that period. I acquainted him with a popular book on physics which exerted a great influence on his whole development. I gave him the first book on mathematics and helpful advice in solving the first geometrical problems. When he was about 13 years old, the flight of his mathematical genius was so high and swift that I could no longer follow. Philosophy then became a subject of our conversations. I advised him to read Kant. The works of this philosopher, incomprehensible to ordinary mortals, seemed to be clear to the young schoolboy. When I made those observations, the thought was often present in my mind that a great scientist would develop out of that child. The expectation has been richly fulfilled. (For a more detailed account see New York *Times*, February 10, 1929. Special Features, p. 11.)

Two distant events simultaneous for an observer in one system, for instance, in a very long ship traveling with uniform speed in a straight line, are non-simultaneous for one observing them from another system, for instance, from the river shore along which the ship is moving. In other words, the simultaneity of distant events is not absolute, but relative, that is, dependent upon the system from which they are observed. Einstein made this discovery and recognized its vast importance for physical research. Its greatness lies in the fact that that thing, simultaneity, did not attract the attention of anybody and he first took notice of it and saw its full import, just as Newton found great significance in a trifle, the fall of an apple to the earth. Let us see now how the relativeness of simultaneity was established.

A ship travels on a river with uniform speed and without noticeable vibration and noise. The water is smooth, the air still. The shore forms a straight line. Under these conditions the passengers are not aware of any motion of their system, the ship, as long as they do not look at its surroundings. When they do observe the shore, the ship is still at rest for them, only the shore is moving from bow to stern. All actions they may perform do not reveal to them any motion of the ship since they proceed exactly in the same manner as on the earth. For an observer on the shore, however, the ship is moving in the direction from stern to bow.

On the top deck of the exceedingly long ship midway between stern and bow is an observer S. In an angle mirror he can see a pole attached to the stern and another pole fastened at the bow. The former carries a white electric lamp (W) and the latter a green one (G). Mr. S turns a switch and the lamps light up. Two events take place, a white flash and a green flash. If S sees them at the same instant in his angle mirror, they are simultaneous for him according to the definition given above.

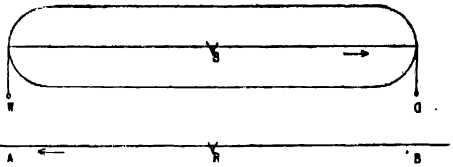

FIG. 1. SHIP AND SHORE

G, GREEN LAMP AT THE BOW; W, WHITE LAMP AT THE STERN; S AND R,. OBSERVERS WITH ANGLE MIRRORS.

On the river shore is another observer R. In an angle mirror he can see the two lamps on the ship. At the instant of their lighting up R is opposite S or midway between the white light (W) and the green one (G). He sees the two flashes but G later than W. The rays from G and W need some time to reach him. Since he moves away from the green ray and toward the white ray—remember that the shore moves from bow to stern—the green ray needs more time to reach him than the white ray, and is therefore seen later. The flashes are perceived by observer R at different instants and he was midway between them when they occurred. Hence they are non-simultaneous for him according to definition.

One can easily compute the amount of the non-simultaneity of the two flashes for observer R. For this purpose we assume greatly exaggerated measures. The ship is 1,000 kilometers long and its speed is 10^5 km. per second. A simple calculation gives the following results. Observer S sees the flashes 1/600 of a second after their occurrence. Observer R sees the white flash 1/800 second after its occurrence and the green flash 1/400 s. after its occurrence. The two flashes are non-simultaneous for him by 1/800 of a second.

The relativeness of simultaneity

proved above has its cause in the circumstance that we do not perceive events directly but indirectly through the light coming from them and light needs time for its propagation. From the stipulation that it travels equally fast in all directions the relativeness of simultaneity follows as a logical consequence.

THE RELATIVITY OF TIME AND OF A SPATIAL LENGTH

The relativeness of simultaneity led Einstein to the discovery that time and a spatial length, too, are relative, that is, different for different observers. This was all the more amazing since time and space were always considered as absolute. No less an authority than Newton emphatically affirmed the absoluteness of time and space which, as he expresses it, have no "reference to any external object."

For the sake of clearness in the further discussion of our subject, attention is called to a point nowhere mentioned, and this is that "time" denotes two things which are not identical, to wit, a duration, *i.e.,* an interval between two events, as in the statement "he traveled three hours," or an instant, as in the statement "he arrived at midnight." An instant and an interval are in time what a point and a length are in space. In the prerelativistic era an interval was considered to be absolute. For instance, if two flashes occurring on the ship are separated by a second as determined by a clock on the ship, it was taken for granted that for an observer on the shore the flashes are also separated by a second of his clock. Einstein discovered that this is not the case, that the observer on the shore finds the interval between the flashes to be more than a second by his clock, *i.e.,* that an interval is relative.

An interval of time stands in connection with the rate of a clock. It follows that the latter, too, must be different for different observers. Einstein found that a clock in motion relative to an observer has for him a slower rate than an equal clock which is at rest relative to him. This may be illustrated as follows. Our ship departs exactly at noon as indicated by a clock on the ship and an equal clock on the shore. After some time observer S finds that his clock is 15 minutes past 12. At this instant the shore clock, as can be proved, has not yet reached for him 15 minutes past 12, but is somewhat behind, let us say, 14 minutes past 12. Conversely at 15 minutes past 12 by the shore clock observer R finds the ship clock to be only 14 minutes past 12, one minute too slow. That all this holds true will be proved later. It follows that both an interval and an instant are relative. An interval of 15 minutes for one observer is only a 14 minutes' interval for another; the instant 15 minutes past 12 for one is 14 minutes past 12 for the other.

Finally a spatial length, absolute according to Newton, has been found by Einstein to be relative, to have a smaller value for an observer relative to whom it is in motion than for another observer relative to whom it is at rest.

TWO HYPOTHESES AND DEFINITION OF THE SPECIAL RELATIVITY THEORY

The factors unknown before and fundamental for the relativity theory are the relativeness of simultaneity, the retardation of a moving clock and the shortening of a moving length. We have proved the first factor but not the other two which imply the relativeness of time and a (spatial) length. The latter proof follows from two hypotheses which form the essential part of the relativity theory.

Certain physical experiments, notably that of Michelson and Morley, gave results which were at variance with firmly established theories. These discrepancies could not be explained and caused no mean perplexity to physicists. Einstein found that two hypotheses furnish the solution of the difficulty. One of them he called the "relativity principle" and the other the "principle (or law) of the constancy of the velocity of light."

(1) *Relativity Principle.* The laws (mathematical equations) for all natural phenomena without exception are the same (have the same form) in all systems which are in uniform rectilinear motion relative to each other. Two implications are contained in this principle. First, all such systems are equivalent for formulating the law of any natural process. Second, by no means is it possible to ascertain absolute uniform rectilinear motion of a system.

(2) *Principle of the Constancy of the Velocity of Light.* Light travels *in vacuo* with the constant velocity c (3.10^5 kms) in all directions independent of the motion of its source. This principle implies that a ray of light has the same velocity c for all observers irrespective of their motion relative to each other.

Between the two principles there was a contradiction, as we shall soon see, owing to the traditional absoluteness of time and a length. Einstein subjected these concepts to a critical examination and found that time and a length are relative. Thereby the conflict between the principles disappeared. The theory which he developed thereupon, harmonizing them, is the "Special Relativity Theory." The term "special" indicates that it is restricted to systems in a special kind of motion, namely, in uniform rectilinear motion. Later he extended the theory to apply to systems in any kind of motion, *i.e.*, also in accelerated and rotary motion. This amplified theory is the "General Relativity Theory."

ADDITION OF VELOCITIES ACCORDING TO CLASSICAL MECHANICS AND CONFLICT BETWEEN THE TWO PRINCIPLES OF THE RELATIVITY THEORY

On the deck of our ship moving with the velocity v, a ball is rolled from stern to bow with the velocity u. What is the value of the ball's velocity U for the observer on the shore? If the ball is at rest on the deck for a second, it travels in this time past observer R the distance v because of the ship's motion. When it rolls, it proceeds for observer S in a second the distance u, hence also the same distance for observer R. Altogether it moves therefore for the latter in a second the distance $u + v$. This sum represents the ball's velocity for observer R: $U = u + v$. Accordingly the velocity sought is obtained by adding the velocities given. This is the mode of the addition of velocities in classical mechanics. It creates a conflict between our two principles. For the preceding considerations must be valid just the same if the ball is replaced by a ray of light. We have then to use c instead of u and we obtain: $U = c + v$. This means that the velocity of the ray is $c + v$ for observer R while for observer S it is c. This contradicts the relativity principle according to which the law of light propagation must have the same form for both observers, can not have the form c for one and the form $c + v$ for the other.

This dilemma disappears when the addition of velocities according to classical mechanics is given up. It is based on the absoluteness of time. It assumes that a second on the ship is also a second on the shore or, generally, that a time interval determined by a clock on the ship has the same value when measured by an equal clock on the shore, *i.e.*, that $t' = t$. But the equality of t' and t is an unproved traditional notion. If we abandon it and establish another relation between t' and t, we find that the same ray of light has the velocity c for both observers. This relation is given through the equation: $t' = tq$, wherein $q = \sqrt{(1 - v^2/c^2)}$. We shall see that from this equation follows that $U = c$, *i.e.*, that a ray of light produced on the ship has the velocity c also for the observer on the shore.

Transformation of Coordinates

The systems ship and shore being inappropriate for general considerations, we must now resort to systems of coordinates. A Cartesian system of coordinates is a frame consisting of three straight lines intersecting each other at right angles in one point, the zero-point. Given such a frame, any point in space can be located through its distance from the zero-point on each axis of the system. The three distances are the space coordinates of the point. To determine an event occurring in it we need to know the time of the event. It is given through a clock at rest in the system. The four variables of an event are designated with the small letters x, y, z, t.

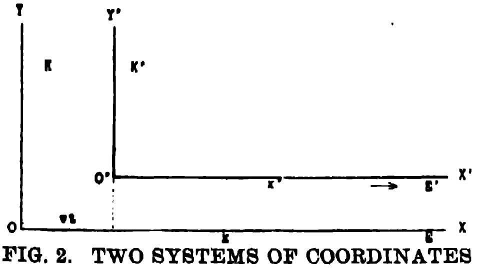

FIG. 2. TWO SYSTEMS OF COORDINATES WITH CORRESPONDING AXES PARALLEL.

We consider two such systems K and K' with corresponding axes parallel and K' in uniform rectilinear motion relative to K with the velocity v and in the direction of the positive X-axis. An event may occur on the X-axis of K and its variables in this system may be given. What are its variables in K'? Since the event takes place on the X-axis, the variables y and z may be neglected. The question is now, what are the variables x' and t' for an event in K when its variables x and t are given?

According to classical mechanics the relations between the two sets of variables are given through these equations:

$$\text{I, (1) } x' = x - vt; \text{ (2) } t' = t.$$

They are called the Galilei-transformations. The relativity theory rejects them. According to it a ray of light must have the same velocity c in both systems. This is the case when the relations sought are expressed through the following equations, called the Lorentz-transformations:

$$\text{II, (1) } x' = (x - vt)/q;$$
$$\text{(2) } t' = (t - vx/c^2)/q; \; q = \sqrt{(1 - v^2/c^2)}.$$

The deduction of these equations is quite simple.

Addition of Velocities according to the Relativity Theory

The equation $U = u + v$ for the addition of velocities in classical mechanics follows from the Galilei-transformations. The ball proceeds in t' seconds of a clock on the ship the distance $x' = ut'$. If we replace x' and t' by their values from the Galilei-transformations, we obtain $x - vt = ut$; $x = t(u + v)$. If t is one second by a clock on the shore, x becomes U, and we obtain: $U = u + v$.

But if we replace x' and t' of the equation $x' = ut'$ by the values from the Lorentz transformations, we arrive at a different formula for U. We have then: $(x - vt)/q = u(t - vx/c^2)/q$; $x(1 + uv/c^2) = t(u + v)$. If t is one second by a clock on the shore, x becomes U and we obtain: $U = (u + v)/(1 + uv/c^2)$. This equation is the theorem of the addition of velocities in the relativity theory.

If we replace the ball by a ray of light, u becomes c and for the velocity of the ray relative to the shore we have the equation: $U = (c + v)/(1 + cv/c^2) =$

$(c+v)/(c+v)/c=c$. This equation shows that the velocity of light can neither be increased nor diminished. For when v is negative, U has also the value c: $U=(c-v)/(1-cv/c^2)=(c-v)/(c-v)/c=c$. The ship's velocity does not enhance nor reduce the light's velocity. Hence a ray of light necessarily has the same velocity for the observer on the ship and the one on the shore.

The two principles of the relativity theory are now in accord since we have furnished the proof that light has the same velocity c for any two observers. We have still to show that time and a length are relative. For this was taken for granted in that proof.

DEFINITION OF TIME

Time has been defined by Einstein as "the position of the little hand of my clock." This determines time as an instant. But since two instants fix an interval, the definition determines also time as an interval.

The definition is adequate for finding the time (instant) of an event happening near the clock but not for a temporal connection between two events remote from each other. In the latter case we need two clocks that have the same rate, are synchronous. Einstein devised an ingenious way of synchronizing two distant clocks A and B through light signals. The stipulation (not assumption) is made that light travels from B to A as fast as from A to B. At 30 seconds past 12 by the A-clock a light ray is sent from A to B. It is reflected from B at 32 seconds past 12 by the B-clock. The two clocks are synchronous if the ray returns to A at 34 seconds past 12 by the A-clock. For since $32-30=34-32$, the light has traveled equally fast in both directions and the stipulation is fulfilled. We have to express all this in general terms. The departure of the ray takes place at the instant t_a of the A-clock, the reflection at the instant t_b of the B-clock, and the return at the instant t'_a of the A-clock. The two clocks are synchronous if $t_b-t_a=t'_a-t_b$. The equation is the definition for the synchronism of two distant clocks at rest relative to each other. The clocks are non-synchronous if the two sides of the equation are unequal. Any number of distant clocks at rest in a given system (ship or shore) can be synchronized in the manner described. We have now gained a definition of time adequate for a temporal correlation of distant events. The time (instant) of an event in a system is the hand-position of a near-by clock at rest in the system and synchronous with a definite clock also at rest in the system and used in it for all determinations of time.

PROOF FOR THE RELATIVITY OF TIME AND OF A SPATIAL LENGTH

We can now prove that clocks synchronous for observer S in system K′ are non-synchronous, a clock in K′ is retarded, and a length in K′ parallel to the X′-axis is shortened for observer R in system K which is in motion relative to K′ with the velocity v, *i.e.*, that time and a spatial length are relative. The proof for these three contentions follows from our two principles. We give it here for the first one.

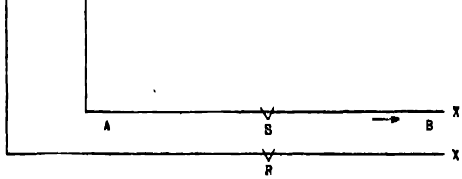

FIG. 3. TWO SYSTEMS OF COORDINATES WITH CORRESPONDING AXES PARALLEL

A AND B, CLOCKS SYNCHRONOUS IN SYSTEM K′.

At the points A and B of the X′-axis are clocks synchronous for S. The other observer R on the X-axis perceives their hands through light illuminating their dials. He notices that at the instant t_a of the A-clock a light flashes up at its dial, is reflected from B at the instant t_b of the B-clock and returns to A at the instant t'_a of the A-clock. The light ray travels towards B with the velocity c for observer R just as for observer S (relativity principle). But for the former the B-clock flees from the ray. The velocity with which the ray overtakes the clock is therefore diminished, only $c-v$. The distance covered by the ray is AB, hence the time consumed in the travel is $AB/(c-v)$. Observer R obtains therefore the equation $t_b - t_a = AB/(c-v)$. At the return the ray has again the velocity c for observer R (law of light propagation). But A moves towards the ray for him, hence the velocity with which the ray reaches A is increased for him, namely, $c+v$. The distance covered is again AB. Observer R finds therefore for the time of the return the equation $t'_a - t_b = AB/(c+v)$. From the two equations follows: $t_b - t_a > t'_a - t_b$. The two clocks are therefore non-synchronous according to the definition for the synchronism of two distant clocks.

The retardation of a clock and the shortening of a length are demonstrable by the same method. It is to be noted that both principles are needed in the preceding proof.

SUMMARY OF THE FUNDAMENTALS OF THE SPECIAL RELATIVITY THEORY

The Special relativity theory consists of two hypotheses and several inferences. For the sake of brevity in summarizing them it is stated that K and K′ mean two systems of coordinates in relative uniform rectilinear motion in the direction of the positive X-axis and R signifies an observer at rest in K and S one at rest in K′.

I. Hypotheses. 1. Relativity Principle. The laws of nature are alike in all systems, in K′ and in K. 2. Law of Light Propagation. The same light ray travels with the velocity c for all observers, for S and for R.

II. Inferences.

1. Two events simultaneous in K′ for S are non-simultaneous for R: simultaneity is relative.
2. Two clocks synchronous in K′ for S are non-synchronous for R.
3. A clock in K′ is retarded for R, has a slower rate for him than his clock.
4. An instant indicated through a clock in K′ is found by observer R to be indicated differently through his clock: time as an instant is relative.
5. Observer R finds an interval between two events in K′ as indicated by a clock in K′ to be too short; he obtains a larger value for it by his clock: time as an interval is relative.
6. A length in K′ parallel to the X′-axis is shorter for R than for S: the value of a spatial length is relative.[2]

CONCLUSION

The equations or formulas called the Lorentz-transformations comprise every one of the six inferences from the two principles and are deducible in a manner well intelligible to the average educated layman. Acquaintance with the deduction and interpretation of these formulas gives the reader a better comprehension of the relativity theory.

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[2] The manuscript of this essay was read by a competent physicist who has made valuable contributions to the relativity theory, Dr. R. A. Wetzel, of the New York City College ("The New Relativity in Physics," *Science*, October 3, 1913.) He approved of the work and called the writer's attention to a book published recently by an opponent of the theory. One of the arguments of this author against the theory is that it makes time and length "relative by definition" and this definition is arbitrary. The writer finds it necessary, therefore, to emphasize that the relativeness of time and length embodied in the inferences enumerated above is not a matter of definition in the theory. They are relative not because "they are defined to be so" but because their relativeness is a cogent conclusion from the two fundamental principles of the theory.

For a still broader knowledge of it he needs information on other items connected with the theory. We can merely mention the most important ones: the observations and experiments which gave the incentive to the development of the theory; notably the experiments of Fizeau and of Michelson and Morley; the consequences of the special relativity theory, such as the union of mass and energy; the equality of inertia and gravitation and the general relativity theory; the consequences from the latter, such as the bending of a ray of light, the anomaly of the planet Mercury, the shifting of the spectral lines of sidereal light; the erroneous popular notions regarding the ether, the fourth dimension and the Euclidean geometry, etc. All these subjects are treated in a book to be published later which follows the method used in this essay. The latter is an extract of the former and intended merely to impart to the lay reader an understanding of the fundamentals of the relativity theory.

IN QUEST OF APOLLO'S SACRED WHITE MICE

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A SNOWY mouse with claret colored eyes is actively tearing paper in her cage upon my desk. She is merely a "tame, white mouse" and but one among millions of her kind raised for scientific study throughout the world to-day. I have been watching her and I have been thinking. In my reaction to her, there is nothing original, because many a man in the past has had his curiosity aroused by just such an albino mouse. Aristotle mentioned a current saying to the effect that the white mice of Asia Minor ruminate. Pallas observed that when white mice are mated to whites all their offspring are albinos like their parents. Darwin learned that whenever white mice are mated to grays there are grays among the immediate progeny and both whites and grays in later generations. Mendel crossed white mice to gray ones, and his biographer suggests that the results of these unpublished experiments may have led him to formulate his theory of heredity for which he later provided overwhelming proof by his classical experiments upon garden peas.

The white mouse has stimulated in me an interest in her origin, and from the data which I have collected we may piece together something of that story.

Some of her past lies hidden away—a bit here, a bit there within a few curious parchment bound volumes of classic tongue, now treasured solely for their great age. Much of the rest is buried forever in the dust that was Babylon and Troy.

Beyond the antiquity of three millennia, at the dim dawn of human record where fact and fiction inseparably commingle, there we must begin if we would trace her lineage. It does not require a great flight of fancy to picture that scene of domestic commotion in the light of a pine-knot fire when the first frightened white mouse was seen by a cave woman to dart from an uncovered grain jar to a crevice in the corner. The woman gave a gasp and excitedly described what she had seen in terms of snow and lightning, only to be squelched by one of the cave men who gruffly assured her that she was imagining things

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[1] The field investigation herein described was provided for by an appointment from Harvard University as Sheldon Fellow in Biology for the year 1930.

again. But when the mouse reappeared from time to time and was seen by other members of the family, the tottering patriarch of the cavern declared *ex cathedra* that it was a good spirit which had come to dwell with them and that its presence in the cave would make them prosper. Whether or not this description bears any relation to the truth, no one can tell, but we do know that somehow white mice found their way definitely into the religious auguries of China, Babylon and Troy, possibly also Carthage, Alexandria and Philistia.

Among Germanic tribes the goddess of fortune appeared as a white mouse. The Slavs and Romans considered it a good omen, while in Japan to-day it is the symbol of Daikoku, the god of wealth.

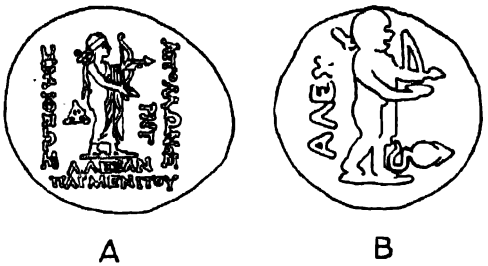
About 1,400 years before Christ, Teucer and his followers landed upon the shore of Asia Minor just below the Dardanelles for the purpose of colonization. Tradition has it that before these Cretans set out from their home land they had been given an oracle commanding them that where they settled there they should build a temple to Apollo, in which shrine they should worship the "earth-born creatures." Now to the nature-adoring ancients each animal had symbolic significance. Witness the popularity of the python cult in Crete. Witness the gifts which the surrendering Scythians presented to Darius to show his complete possession of all they had owned. They sent him a mouse, a frog and a bird, symbolizing their land, sea and sky, respectively. The choice of the mouse by the Trojans as the sacred symbol of Apollo is explained by the following Pontic legend:

For a long time the invading Teucri were restricted to the shore by the aboriginal Pontians, with whom they continuously contested in arms. A decisive victory for the Cretans was accredited to the mice which their Apollo caused to gnaw the leather from the shields of the enemy during the night preceding the final battle. After conquering Pontus the colonists toiled many days to erect by the winding brook Scamander the high-walled Pride of Priam. Nor did the Trojans forget in their prosperity the humble source of their salvation, but in gratitude they constructed upon the adjacent Isle of Tenedos their first temple to Apollo, a smintheon, where mice were sacrosanct.

Several Greek and Roman historians visited the Troad temples and described in detail a marble sanctuary teeming with gray mice raised at public expense. More holy than all the rest were a family of white ones having their nest under the altar itself. Coins of the Troad frequently bear representations of the archaic cultus statue of Apollo Smintheus and occasionally a sacred mouse.

Apollo Smintheus, besides being god of the bow, had among his dominant attributes soothsaying and healing. It was to Herophila, sibyl of the Mouse Apollo, that Queen Hecuba turned in despair for the interpretation of her dream forecasting the collapse of Troy and the fate of herself and family. Possibly, Herophila consulted the white mice, which method of augury had long been practiced in Babylon and made known in Asia Minor through contact with the Persians. During the life of Christ the mice raised in the temple were used extensively for purposes of prognostication, and Pliny records that if there be many white ones bred, it is a good sign which predicts coming prosperity. He recounts also the alleged observation of soothsayers that the size and "numbers of the filaments of their liver and bowels wax and wane with the moon."

The healing qualities of mice were early exploited by the priests of Apollo, and the devout often carried temple



APOLLO SMINTHEUS APPEARS UPON COINS OF ALEXANDRIA TROAS (A) AND TENEDOS (B). THE LATTER SHOWS A SACRED MOUSE

mice into their homes in time of sickness. The mere presence of a sacred mouse in the sick room effected a cure. A story goes that if the curative mouse were not returned to the temple, it would find its way back of its own accord. Galen prescribed equal parts of cock's gall, mouse blood and woman's milk dried and powdered as a cure for cataract. Pliny said that a poultice made from a freshly killed mouse was an excellent remedy for snake bites. The Romans employed mouse dung in the treatment of baldness. The "Father of Medicine," Hippocrates, was born far south of the Troad at Cos, an island extolling the greater virtues of the serpent. His scepticism is evident. He says that he did not even go to the trouble of testing the virtue of mouse blood for warts, prescribed by his colleagues, because he had a magic stone with lumps upon it which had already proved to be an efficient remedy.

Murine formulae, probably of Greek origin, appear from time to time in the writings of the middle ages. St. Hildegard of Bingen recounts that mice are a cure for epilepsy. The manuscript known as Picatrix endorses fumigation against disease with a smudge prepared from 14 bats and 24 mice. Peter of Albano employs mouse dung as a cure for poisons. As a present-day hangover of medieval black art may be cited the occasional feeding of stewed mice to children in Boston and New York to prevent bed wetting. This cure is prescribed in London Pharmacopoeia of 1667. Peasants of Switzerland recommend that a stewed mouse be eaten every two weeks in order to prevent toothache. The persistent local impress of the Sminthian cult is evident in that modern Greeks call mice "pontiki" (from the Trojan region of Pontus), and both Turks and Greeks alike prepare "mouse oil" as a panacea for human ailments. Nearly all variations of the formula agree that about 10 newborn mice must be dropped into a liter of olive oil and allowed to dissolve a fortnight in the sunshine with occasional shaking. At Keyekli, opposite Tenedos and about 10 miles from the mound of Troy, the Turks add as necessary ingredients the flowers of two small composites (*Artemisia arborescens* L.) one yellow and one white. The white one is said to be the more potent. On the Island of Chios only one flower is used. In Constantinople no flowers are necessary. A Cretan informed me that in some parts of his land the young of an albino mouse are much superior to the common gray variety, while a more heretical Cretan confided secretly his candid opinion that old olive oil lacking the mice and herbs was almost as effective.

The sacred white mice of Pontus are mentioned in the writings of Aristotle, Strabo, Aelian and Suida, while other writers such as Pliny, Hesychius, Albertus, Apostolius, Gesner, Johnson, Pallas and Darwin speak of the albino variety in general.

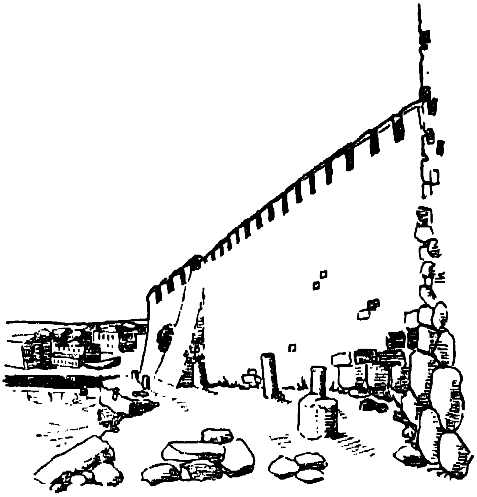
So strong became the cult of the mouse god that centers of worship were located at Chryse, Killa, and Tenedos, Alexandria, Hamaxitos, Larissaia, Parion, Arisba, Methymna and Magnesia.

With the mouse cult at the height of its popularity in the spheres of prophecy and therapeutics the loquacious St. Paul set out upon his missionary journey through Asia Minor vehemently denouncing local religious practices wherever he went. In order to avoid difficulties, the Holy Ghost wisely suffered him not to go into Bithynia nor to preach in Asia (Pontus), two regions where men worshipped the ancient mouse god. Twice he sailed in silence past the famous mouse temples on the mainland and those upon the islands of Mitylene and Tenedos. But upon his return from Athens, however, St. Paul was so pent up that he could stand it no longer and indulged himself by delivering an all-night sermon at Alexandria Troas against the Holy Ghost's orders. Then, perchance, to avoid Apollo's irate priests at the wharf from which his boat was scheduled to sail in the morning, he retreated over a back-road to the town of Assos (Beiram), where he had previously arranged that his comrades on the boat should pick him up.

The mouse god was so deeply rooted in the Troad that it may not have been Christianity at all but rather Mohammedanism that overthrew Apollo Smintheus as a local god and wrecked the last of his shrines at the time of the Turkish conquest. By this time white mice had appeared in the monastic writings of Europe.

But are we to conclude that the active creature upon my desk is really a descendant of Apollo's sacred mice?

We can not be sure of the sources of information drawn upon by Pliny, Allianus, Suida or Albertus. Aristotle was of Ionian stock and doubtlessly visited nearby Pontus. Strabo definitely inspected a Sminthian temple, perhaps at Alexandria Troas. Apostolius was born in Constantinople and probably traveled in the Troad. The later historians appear to be writing of white mice raised in cages in the monasteries of Europe. From these latter stocks we have doubtlessly obtained the albinos of the mouse fancy and the scientific laboratory. If the early writers of Asia Minor are speaking of the same species as are the Christian fathers (and they appear to be), then we may say definitely that Apollo's mice were albinos of the species *Mus musculus* and that our laboratory mice are probably descended from the temples of Apollo.



THE TURKISH FORT AT TENEDOS CONTAINS MUCH STONE FROM THE MOUSE TEMPLE

FIVE GRANITE COLUMNS AND A MARBLE BASE MAY BE SEEN ALONG THE WHARF.

It is quite clear that the mice used in medicinal formulae during the middle ages and to-day are the common house mouse. Yet from this evidence it is impossible to conclude that the sacred mice of the Sminthian cult were of the same species. How are we to know but that the mice of Apollo were field mice, either *Apodemus* or *Microtus*, or the rat *Rattus alexandrinus* or even moles such as *Spalax*? Indeed, this latter creature has a pale coat and is known to the Turks as "Beyaz fare," the white mouse.

Although we may at first thought associate "Beyaz fare" with the white mice having their nest under Apollo's altar, anatomical and behavioristic considerations rule out *Spalax*. The temple mice appeared in both the gray and the white form. *Spalax* of this region is always pale. The sacred mice depicted upon coins are long tailed, whereas *Spalax* is short tailed. Besides, *Spalax* could never be tamed. Gesner says: "sicut Aeschylus in Sisypho testatur cum ait: Sed agrestis quis est Smintheus." In spite of this statement, the crop destroyer of the Troad, *Microtus*, is excluded on account of its rudimentary tail.

This leaves *Apodemus sylvaticus*, *Rattus alexandrinus* and *Mus musculus*. It is true that all three of these animals could be tamed as were the sacred mice. The fact that one finds no *Rattus alexandrinus* in the Troad to-day proves nothing, because *Rattus rattus* and *Rattus norvegicus* may have both in turn replaced it in this region since classical times. The strongest evidence against it is the fact that it is not easily domesticated. Although *Apodemus sylvaticus* may be tamed with greater ease than *Rattus alexandrinus*, *Mus musculus* more commonly associates itself with men and is much more adaptable to human haunts. I caught in a wheat field near Soma (Asia Minor) a female specimen of *Mus musculus gentilis* which was so tame that it would eat within an inch of my hand two days after its capture.

In the summer of 1930 I visited the island of Tenedos. There I trapped in the town, the old fort, two windmills and a peasant's mud hut. At Tenedos there were collected about 40 specimens, all *Mus musculus!* I took five mice on the adjacent mainland of Keykeli (between Troy and Alexandria Troas), all *Mus musculus!* At Kalloni (Mitylene) near ancient Arisba were procured eight specimens, again all *Mus musculus*. From such samples of the mouse population it is evident that *musculus* is the predominating mouse of the region. If we wish to make sub-varietal distinctions, these were all of the gray-bellied European form, and only far inland from Smyrna did I encounter the light-bellied *gentilis* sub-variety. As grain has always moved from the mainland to the islands and never *vice versa*, one would expect the white-bellied form to be gradually encroaching upon the territory of the European form. Thus gray-bellied *Mus musculus* has probably inhabited this region ever since Trojan times. Curiously enough, the albinos of the scientific laboratory were originally of the gray-bellied European stock, as proven by their conformation and breeding.

According to calculations upon the persistence of Mendelian recessive characters in strains mating at random, it is almost impossible to eliminate such a character as albinism from a wild stock, once it has become firmly established. We may be certain that Apollo's sacred mice, when turned loose in devout homes upon their missions of mercy, contaminated stocks of their own species in the neighborhood of the temple. Thus, albinism would be expected to persist among the mice of the locality in spite of later selection by such enemies as weasels and owls, barring general catastrophe, because gray mice may carry latently the hereditary factor for albinism. Such grays carrying albinism always throw offspring in the ratio of three grays to one albino when mated to other such carriers. This means that perhaps an occasional albino might still be found near the site of Apollo's temple to-day. It should identify for us the species of Apollo's mice. It was not my fortune to capture a white mouse, nor did I inquire concerning them, lest the inhabitants, eager to please, should invent tales for me.

One evening I sat before a coffee house on Tenedos but a stone's throw from the site of the first mouse temple. Half a dozen Greeks and Turks had been chatting with me over the hot cups. During a lull in the conversation I looked out over the blue sea to the visible mainland where I could view the shore of Troy to the left and that of Alexandria Troas to the right, and I dreamed concerning the prosperous days of that now barren land. My imagination jumped from the sojourn of Menelaus on Tenedos across to the fall of Troy and thence down to Alexandria, where I had recently seen the curious foundation of a palace or a temple. Breaking the silence and startling me, an old wine merchant in the group said off-hand that in the summer of 1929 a white mouse with pink eyes appeared in his house. He used to place food for it until it became fairly tame but never tame enough to be handled. This mouse could have been none other than *Mus musculus* from his description.

Thus it is probable that Apollo's sacred white mice on Tenedos have transmitted albinism for about 2,200 years or 8,800 generations, the longest heredity of a simple variation of which we have written record. Thus the mice of the Sminthian temples used for auguries and the curing of human ills were probably *Mus musculus,* whose present-day descendants, like the industrious one on my desk, swarm our scientific laboratories, even surpassing the traditions of their glorious past by nobly contributing to our knowledge of cancer, tuberculosis and many other diseases and safeguarding our lives with the sacrifice of theirs in the testing of sera.

Note:—I have not considered the remote possibility of a new mutation to albinism, which has never been observed among laboratory mice, so far as I am aware.

THE PUBLIC SQUARE AT TENEDOS IS THE SITE WHERE STOOD THE FIRST TEMPLE TO THE MOUSE GOD, APOLLO

BIOLOGY IN SHAKESPEARE

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THE term "biology" for our present purpose is used in a very wide sense, for by biology we understand all those sciences which have anything whatever to do with life.

But we shall not enter upon a catalogue of all the plants and animals referred to by Shakespeare, interesting undoubtedly as that study might be made in competent hands, nor shall we discourse on the various diseases alluded to by our and the world's greatest dramatist.

Let us, rather, consider a few allusions to such subjects as have, in our present-day understanding of them, some distinctly physiological or psychological interest.

We might begin with sleep, of which it is certain that in Shakespeare's time there was no physiological theory.

While all physiologists are not even now agreed on what exactly it is that induces that state of the nervous system and of the mind which we call "sleep," yet there is considerable unanimity about the chief cooperating causal factors.

We recognize that the accumulation of certain chemical substances, which we may call "fatigue-poisons," circulating in the blood, coupled with a diminution of the vigor of the circulation through the brain, along with the absence of sensations and of the more strictly intellectual activities, predisposes to sleep. There are, therefore, at least four participating factors which we may call the chemical, the vascular, the sensory and the ideational, respectively.

And, conversely, the absence of fatigue, too much blood in the brain, the presence of sensations and of mental preoccupations are responsible for the corresponding insomnias.

Shakespeare has noticed at least two of these factors in the familiar address to "Sleep" by the king in "Henry IV" (Part II, Act iii, Sc. 1).

How many thousands of my poorest subjects
Are at this hour asleep! O sleep, O gentle sleep,
Nature's soft nurse how have I frightened thee,
That thou no more wilt weigh my eyelids down,
And steep my senses in forgetfulness?
Why rather, sleep, liest thou in smoky cribs
Upon uneasy pallets, stretching thee,
And hush'd with buzzing night-flies to thy slumber,
Than in the perfumed chambers of the great
Under the canopies of costly state,
And lull'd with sounds of sweetest melody?

Wilt thou upon the high and giddy mast
Seal up the ship-boy's eyes and rock his brains
In cradle of the rude imperious surge;
Canst thou, O partial sleep! give thy repose
To the wet sea-boy in an hour so rude,
And in the calmest and most stillest night,
With all appliances and means to boot,
Deny it to a king? Then, happy low, lie down!
Uneasy lies the head that wears a crown.

In this famous soliloquy Shakespeare contrasts the insomnia of the king brought on by the mental factor—the cares of state—with the sound sleep of his fatigued subjects, and especially with the chemically induced slumbers of the tired-out "sea-boy." The sleep of the latter is of that type which even the storm can not disturb, and which is not accompanied by the usual loss of tone of the muscles, for he does not lose his balance or fall from the rigging.

This maintenance of the posture is in contrast with the loss of muscular tone in drunkenness, for, says Hastings, in "Richard III" (iii, 4)—

Like a drunken sailor on a mast,
Ready with every nod to tumble down
Into the fatal bowels of the deep.

It is well known that in certain cases the very deepest type of fatigue-induced sleep is compatible with the maintenance of the posture and equilibrium, as when in the "good old days" postilions feel asleep on horseback and did not roll off, when to-day cross-channel swimmers are found swimming asleep, when persons thoroughly exhausted have walked miles in their sleep, and finally when sentries have slept without falling down.

The same idea of chemically induced sleep is given us in Cymbeline (Act iii, Sc. 6)—"weariness can snore upon the flint when resty Sloth finds the down pillow hard." And this is echoed by these words from Ecclesiastes—"The sleep of a laboring man is sweet" (V. 12).

The mental factor in sleeplessness is well described in "Romeo and Juliet" (ii, 3):

Care keeps his watch in every old man's eye;
And where care lodges, sleep will never lie.

The phrase, "To purge him of that humor that presses him from sleep," which occurs in "A Winter's Tale" (ii, 3), is probably an allusion to what in modern language we should call a toxic source of insomnia. But of course it refers to the very old view of the four "humors" which from the time of Hippocrates were assumed to be the sources of disease—blood, phlegm, yellow bile and black bile.

Sleep, as every one knows, is the great restorer of energy to the nervous system; for prolonged sleeplessness is much more damaging than lack of food. A sleepless animal at the end of three to four days is as miserable as a starved one at the end of ten to fifteen.

This aspect of things is well described in "Macbeth" (ii, 2):

Macbeth does murder sleep! the innocent sleep,
Sleep that knits up the ravell'd sleave of care,
The death of each day's life, sore labour's bath,
Balm of hurt wounds, great Nature's second course,
Chief nourishment in life's feast.

We are given here six different similes to express the same idea.

Sleep is literally a nourisher in that a certain amount of sleep represents a certain amount of food; we are more hungry after four waking hours than after eight to ten hours of sleep.

Puppies deprived of sleep died at the end of five days, although they were taking food; whereas controls, allowed to sleep as much as they wished, but from which food was entirely withheld, survived to the twentieth day. Shakespeare has embodied the substance of this modern knowledge in the passages just quoted.

In sound sleep, the sensory centers are not accessible to impulses from outside, not even to painful impressions; hence it is perfectly true that "He that sleeps feels not the toothache" ("Cymbeline," v, 4).

The power of sleep to banish sorrow in total unconsciousness is well put by Helena in "A Midsummer Night's Dream" (iii, 2):

Sleep, that sometimes shuts up sorrow's eye,
Steal me awhile from mine own company.

Shakespeare, however, shared the popular tendency to regard sleep as closely resembling death. Physiologically this is quite wrong: sleep is, as he himself has told us, the great restorer; in sleep we recuperate, we sleep to wake.

But when he exclaims in "Cymbeline," "Sleep, thou ape of death" (ii, 2), and again, "Shake off this drowsy sleep, death's counterfeit" ("Macbeth," ii, 3), he is in illustrious company, for Shelley wrote, "Death and his brother sleep" (Queen Mab); and Tennyson called sleep, "Death's twin brother."

Any references that Shakespeare makes to the vascular system—to the heart, arteries, veins and blood—must be peculiarly interesting to us, seeing that our great poet was a contemporary of that other illustrious Englishman, Dr. William Harvey, the discoverer of the circulation of the blood. Shakespeare died one week after Harvey gave his first public lecture as Lumleian Lecturer at the College of Physicians on April 16, 1616.

Shakespeare was fourteen years older than Harvey, for he was born in 1564 and Harvey in 1578, so that as Harvey died in 1657 they were contemporaries for 38 years.

But there is not much likelihood of their having met, for Harvey was a student of medicine at Padua from 1598 to 1602, during the very time when Shakespeare in England was at the height of his activity.

Some uncritical writers have assumed that because Shakespeare and Harvey were contemporary, Shakespeare must have known of the new views of the circulation of the blood which were disturbing the anatomists and the medical schools of Europe. But even if the two great men ever met, the young physician was not in the least likely to discuss with his senior, the actor, a quite revolutionary view of a matter of pure physiology.

Harvey did not publish his discovery until 1628, twelve years after Shakespeare was in his grave.

Some critics have thoughtlessly suggested that Shakespeare might have learned of the Harveian doctrines from his son-in-law, Dr. Hall, of Stratford-on-Avon; but Shakespeare's daughter married Dr. Hall as early as 1607, twenty-one years before the celebrated "De Motu" saw the light at Frankfort-on-the-Main. We have no reason to suppose that worthy Dr. Hall was endowed with any transcendental intuitions regarding matters vascular.

From these considerations we should *not* expect Shakespeare to have been acquainted with the true knowledge of the circulation; and as a matter of fact there is not one word in all his writings to suggest that he did know of it.

In this respect at least he is not beyond his age; on the contrary, he reflects it. His vascular physiology is entirely pre-Harveian, in other words, it is Galenical; it is in accord with the views taught in the medical schools of Europe for 1,400 years, the views of Claudius Galen, that great dictator in all matters physiological.

Galen, although resident in Rome, physician first to the Emperor Marcus Aurelius and later to Commodus, and surgeon to the school of gladiators, was of Greek descent. He was born in the Greek colony of Pergamos in Asia Minor about 130 A. D.

Many of his views, as we might suppose, were based on the still older ones of Hippocrates, of Aristotle and of the anatomists of the famous school of medicine at Alexandria at its zenith, about 300 B. C.

At least the names of these two great masters in medicine were known to Shakespeare, for he makes Sir Hugh Evans in the "Merry Wives" say of Dr. Caius (iii, 1)—"He has no more knowledge in Hibbocrates and Galen—and he is a knave besides." Galen is mentioned again along with Hippocrates, in the same play. "What says my Hippocrates? My Galen?" And once more in "Coriolanus" we have the phrase—"The most sovereign prescription in Galen" (ii, 1). Lastly Galen is mentioned along with Paracelsus in "All's Well" (ii, 3) where Parolles refers to "Galen and Paracelsus" as "all the learned and authentic fellows."

This is interesting in that Paracelsus had died only twenty-three years before the date of Shakespeare's birth.

Before Galen's time it was believed

that blood was found in the veins only, that in them it traveled both up and down for the nourishment of the body; and, since the large arteries after death are found to be empty, it was taught that these vessels in life contained not blood but only "vital spirits."

Galen, by tying a living artery in two places and cutting out the ligated piece, showed at once that during life arteries did contain blood.

To appreciate the pre-Harveian physiology we must understand the Galenical doctrine of spirits, which very briefly was: The food, digested in the intestines, was absorbed thence and carried to the liver, where after elaboration it became possessed of "natural spirits." Still as crude blood it passed to the right side of the heart, whence it went up and down the veins in the manner of a tide. In modern language, "natural spirits" were the equivalent of "power of nourishing." Some of this crude or venous blood was supposed to percolate through the septum dividing the right from the left side of the heart. There are, in reality, no pores, but they were not denied until by Vesalius in 1543, and experimentally disproved later by Harvey.

The blood on the left side of the heart was then supposed to be mixed with air drawn into it by the act of breathing.

This air cooled "the innate heat of the heart," and engendered in the now scarlet blood the "vital spirits" which (carried in the bright blood reaching the tissues by the arteries) conferred on these tissues their capacities for performing their functions.

Finally, said Galen, blood plus vital spirits on reaching the brain produced there the third and last order of spirits, "the animal," the distillation of which was supposed to go on in the cavities or ventricles of the brain.

In this sense the brain was a retort or still, where animal spirits were distilled; and it must be in allusion to this that Shakespeare uses the word "a limbeck" or "alembic" (*al ambeq*) the chemical, medieval Arabic word for a retort or still.

Lady Macbeth is speaking—

> . . . his two chamberlains
> Will I with wine and wassail so convince,
> That memory, that warder of the brain,
> Shall be a fume; and the receipt of reason
> A limbeck only.
>
> —*Macbeth, i, 7.*

as much as to say, the state of intoxication will convert the brain into a retort which can not perform its wonted function of distilling the spirits.

Cornelius, the doctor in "Cymbeline," speaking of the poison with which the queen is working, says:

> There is no danger in what show of death it makes,
> More than the locking up the spirits for a time,
> To be more fresh, reviving.

The word "animal," used here for the third order of spirit, does not mean belonging to a beast; it means "pertaining to the soul" or *anima,* the Latin equivalent of the Greek psyche (soul or life); the full Latin expression being "spiritus animalis." These "animal spirits," which survive in our everyday speech, were to Galen what nerve-impulses are to us—the impulses which ascend and descend the nerve-fibers as sensory and motor innervations, respectively.

A good deal of this old physiology is contained in the speech of Meninius Agrippa, the friend of Coriolanus, who makes "the belly" speak as follows:

> True it is, my incorporate friends,
> That I receive the general food at first
> Which you do live upon; and fit it is,
> Because I am the store-house and the shop
> Of the whole body; but if you do remember,
> I send it through the rivers of your blood
> Even to the court, the heart—to the seat o' the brain,
> And through the cranks and offices of man;

The strongest nerves and small inferior veins
From me receive that natural competency
Whereby they live.

The physiology of this well-known passage is indeed Galenical, but not all of it is erroneous: the abdomen does receive the food upon which ultimately the whole body subsists; it is sent by the currents—rivers—of blood to the heart, and some of it reaches the brain. But the very phrase, "rivers of your blood," precludes the idea of a circulation, a returning of the same blood. Galen taught an up and down or tide-like flow; Harvey a flow in one direction and a continual returning—they are totally different things.

In the following passage from "Coriolanus" (v, 1) we have again very much the same ideas regarding the functions of the veins:

The veins unfill'd, our blood is cold, and then
We pout upon the morning, are unapt
To give or to forgive; but when we have
stuffed
These pipes and these conveyances of our blood
With wine and feeding, we have suppler souls
Than in our priest-like fasts.

Shakespeare certainly recognizes the preëminence of the heart and its susceptibility to be disturbed by emotional states, as when he makes Macbeth exclaim:

Whose horrid image doth unfix my hair,
And make my seated heart knock at my ribs.
—*Macbeth, i, 3.*

It is an emotional, reflex, pilo-motor effect, and an emotional, reflex cardio-acceleration respectively that are here being described in picturesque but not inaccurate language.

The passage in "Julius Caesar" (ii, 1) in which Brutus declares

You are my true and honourable wife,
As dear to me, as are the ruddy drops
That visit my sad heart.

has actually been taken to prove that Shakespeare not only knew of the circulation but anticipated Harvey in his discovery.

Now this is really carrying things too far; we may charitably excuse it as excess of hero-worship, but it is perilously near to childishness.

It is true that Shakespeare assigns to the heart a preëminence beyond what it was accorded in the Galenical physiology; the notion indeed is ever before him, as when he says:

O England, model to thy inward greatness,
Like little body with a mighty heart.
—*Henry V, Chorus before Act ii.*

He has no doubt whatever that in fainting it is the heart that is at fault, and that bad news in particular can be a cause, for in "Richard III" (iv, 1) Queen Elizabeth says:

Ah, cut my lace asunder,
That my pent heart may have some scope to
beat,
Or else I swoon with this dead killing news.

But another type of fainting, that due to the sight of blood, was quite familiar to him, for we have in "As You Like It" (iv, 3), "Many swoon when they do look on blood." Present-day physiology calls it an inhibitory, sensori-vascular reflex action.

Shakespeare knew perfectly well that fresh air is necessary to revive the fainting person, for we are told (Henry IV, Part II, iv, 4), "Stand from him, give him air, he'll straight be well," another sensori-vascular reflex; but we do not therefore infer from this that Shakespeare had taken out a course of lectures and demonstrations in "first aid"; no, not even although he says in "Measure for Measure" (ii, 4)

So play the foolish throngs with one that
swoons;
Come all to help him, and so stop the air
By which he should revive.

Just as in our everyday parlance the veins come in for more attention than the arteries, so too in the plays the veins are more frequently referred to. The blueness of the veins is noticed in "Antony and Cleopatra"—"my bluest veins" (ii, 5).

But there is at least one definite allusion to the arteries in "Love's Labor Lost" (iv, 3) where Biron speaks of "the nimble spirits in the arteries." This is clearly a reference to the vital (arterial) spirits of the Galenical physiology: but we are almost compelled to think that Shakespeare regarded the arteries as devoid of blood, which was the pre-Galenical view.

As a matter of fact Shakespeare's physiology of arteries is a little confused, for he makes Hamlet say (Hamlet, i, 4):

> My fate cries out,
> And makes each petty artery in this body
> As hardy as the Nemean lion's nerve.

The expression in King John (iii, 3) —"blood runs tickling up and down the veins," is in perfect agreement with pre-Harveian teaching. Even if the word here should, more appropriately, be "trickling," it would not alter the sense.

Shakespeare associates life with the blood in the veins, as when we read in "King John" (iii, 3), "Whiles warm life plays in that infant's veins," which is clearly an allusion to the very old Biblical and Hippocratic belief that "the blood is the life." Doubtless it was through watching the sacrificial animal die, as its blood ebbed away, that gave rise to this ancient and very natural belief. In the same strain we have in "King John" (v, 7), "The life of all his blood is touched corruptibly."

There is a passage in "Hamlet" (i, 5) which may refer to the veins and even to the valves in them, where Hamlet, speaking of the poison, says, "it courses through the natural gates and alleys of the body."

Shakespeare was acquainted with at least one property of the blood—its odor—known in modern physiology as the "halitus sanguinis"; for in that very remarkable scene in Dunsinane castle, Lady Macbeth, walking in her sleep, is shown trying to wash away the stain of the blood of the murdered king and saying (Macbeth, v, 1), "Here's the smell of the blood still; all the perfumes of Arabia will not sweeten this little hand." She has just asked, "Who would have thought the old man to have had so much blood in him?"

Related both to the circulatory and to the nervous system is the action of alcohol; and much that Shakespeare says about this has quite the modern ring, as, for instance, in the passage in King Henry IV (II, iv, 3) where the effects of "sherris-sack" are described in detail by the fat knight:

> The second property of your excellent sherris is—the warming of the blood which, before cold and settled, left the liver white and pale which is the badge of pusillanimity and cowardice; but the sherris warms it and makes it course from the inwards to the parts extreme.
>
> It illumineth the face which as a beacon gives warning to all the rest of this little kingdom, man, to arm; and then the vital commoners and inland petty spirits muster me all to their captain, the heart.

There is much good physiology here; alcohol, in not-too-large quantity, is a tonic or stimulant to the heart in that it causes it to drive the blood more forcibly into the peripheral vessels, including those of the face. In the phrase, "their captain, the heart," we see Shakespeare once more recognizing the functional preëminence of that organ. We notice, too, the reference to "the spirits."

The value of alcohol as a general stimulant is brought out when the dying Antony exclaims:

> I am dying, Egypt, dying,
> Give me some wine, and let me speak a little.

The notion that the relatively bloodless liver would be pale is not entirely fantastic. That great gland if washed free of blood does have a pale, grayish hue; and if therefore a blood-filled liver is the physical basis of courage, there is nothing absurd in the idea that a bloodless and therefore pale liver would be related to cowardice.

In "King Lear" (iv, 2) we have Goneril exclaiming, "milk-livered man." The same sort of idea occurs in "Measure for Measure" (iv, 3), where Lucio says, "O pretty Isabella; I am pale at mine heart to see thine eyes so red."

We should compare this with Lady Macbeth's words—"I shame to wear a heart so white" (Macbeth, ii, 2) and with Gratiano's ("Merchant of Venice," i, 1):

> And let my liver rather heat with wine
> Than my heart cool with mortifying groans.

Shapespeare is in no doubt that it is on the brain that alcohol ultimately acts, for he makes Cassio refuse Iago's offer of a stoop of wine in these words:

> Not tonight, good Iago; I have very poor and unhappy brains for drinking; I could well wish courtesy would invent some other custom of entertainment.—*Othello, ii, 3.*

And again; "O that men should put an enemy into their mouths to steal away their brains" (*Ibid*); and once again when Falstaff tells us (Henry IV, Part II, iv, 3):

> A good sherris-sack hath a two-fold operation in it. It ascends me into the brain; drives me there all the foolish and dull and crudy vapors which environ it.

In the "Twelfth Night" we have the three stages of drunkenness described by the clown: Olivia asks, "What's a drunken man like, fool?" Clown: "Like a drowned man, a fool and a madman; one draught above heat makes him a fool, the second mads him, and a third drowns him."

It is literally true that death in alcoholic poisoning occurs through paralysis of the respiratory center with the symptoms, therefore, of asphyxia as from drowning.

The physiology of digestion and of the allied subject of starvation is referred to with marvelous insight. Thus, when Gaunt says in "Richard II" (i, 3)—"Things sweet to taste prove in digestion sour," it is literally true, whether we confine the word "sweet" to sugars or allow it to refer to the two other principal food-stuffs.

The sugars before being finally incorporated into the tissues, it is thought, go through the stage of lactic acid; and milk-sugar in particular is fermented into that acid with the greatest ease.

It is also a fact of biological chemistry that the chief food-stuffs, the proteins, undergo hydrational changes with the formation of amino-acids, and it is these that are absorbed; further the neutral fats, before they are digested, are split up into glycerine and the corresponding fatty acids, the latter being distinctly sour products.

The baneful effect upon digestion of unpleasant emotions—worry, sorrow, etc.—was perfectly well known to Shakespeare, for he makes the Abbess in the "Comedy of Errors" say (v, 1)—"Unquiet meals make ill digestion."

The unraveling of the complete nervous mechanism by which the digestive function is influenced by emotional states for good or ill, has been fully worked out only within quite recent years by the great Russian physiologist, Pavlov.

Pavlov has shown that all pleasant and refining conditions—music, flowers, change of clothes, fine linen, silver, cut glass, etc.—tend to produce that state of good digestion and appetite learnedly called Eupepsia. This is the sort of thing Shakespeare meant when he said: "The sauce to meat is ceremony" ("Macbeth," iii, 4); and in a line or two later,

> Now good digestion wait on appetite,
> And health on both.

One other example of a pleasant emotion promoting a tonic effect for the whole body is in "King Richard III," (v, 2), where Richmond exclaims:

True hope is swift and flies with swallow's wings,
Kings it makes gods, and meaner creatures kings.

This state of mental exhilaration is referred to in "Henry IV" (Part II, iv, 4), when Prince Henry says: "If he be sick with joy, he will recover without physic."

No less full of insight is the description of the biology of starvation: "I sup upon myself, and so shall starve with feeding" (Coriolanus, iv, 2).

What happens in inanition is that the heart and central nervous system are living upon the fat and muscles of the body generally. These "two noble" tissues are literally subsisting upon all the others; and it is, therefore, biologically correct to say that in starvation one feeds upon oneself.

Shakespeare had grasped the biological significance of life as something *sui generis,* something which if quenched can never be revived. This was far from being the clear-cut belief in his day: life as something unique, whether in plant or animal, impossible of being derived from the non-living, was by no means the doctrine of the learned about 1600, nor for two hundred years afterwards. The belief in Abiogenesis, that is life arising from the non-living, was not finally given up until after the work of Pasteur and of Tyndall in the seventies of the last century.

But in that most painful scene in that most painful of plays—"Othello" (v, 2), Shakespeare makes the Moor, on entering the bed-chamber where Desdemona is asleep with a light beside her, thus soliloquize when he has determined to smother her:

Yet she must die, else she'll betray more men;
Put out the light, and then—Put out the light!
If I quench thee, thou flaming minister,
I can again thy former light restore,
Should I repent me—but once put out thy light,
Thou cunning'st pattern of excelling nature,
I know not where is that Promethean heat
That can thy light relume. When I have plucked thy rose
I can not give it vital growth again;
It needs must wither.

Here, it seems to me, Shakespeare is expressing poetically the essential difference between vitality and any manifestation of energy in the world of the non-living.

Shakespeare seems to have been perfectly aware of the breathing test for cases of apparent death; for does not the King in "King Lear" (v, 3) say:

I know when one is dead and when one lives,
She's dead as earth—lend me a looking-glass,
If that her breath will mist or stain the stone,
Why, then she lives.

And Lear uses the feather test, too: "This feather stirs: she lives" (v, 8).

Shakespeare is fully aware of the great value of rest to the living being, for we have the doctor in the same play (Lear, iv, 4) assuring Cordelia that "Our foster-nurse of nature is repose"; and the expression "life-preserving rest" in the "Comedy of Errors" (v, 1) is in fullest accord with the most recent demonstrations in biology: anabolism is the learned term given to the vital processes involved in rest.

With regard to drugs, although Macbeth is made to say—"Throw physic to the dogs; I'll none of it" (v, 3), yet Shakespeare evidently did not despise medicines, for Cymbeline avers, "By medicine life may be prolonged; yet death will seize the doctor too" (Cymbeline, v, 5).

Apropos of drugs, we have in the same play (i, 6) two references to what in some quarters is called "vivisection": they are both by Cornelius, the physician, who, speaking of the queen, says:—

> Those she has
> Will stupify and dull the sense awhile,
> Which first perchance she'll prove on cats and dogs.
> Then afterwards up higher.

And again in Act v, scene 5:

> The Queen, Sir, very often importuned me to temper
> Poisons for her . . . still pretending
> The satisfaction of her knowledge only
> In killing creatures vile, as cats and dogs
> Of no esteem.

In the description of Falstaff's death (Henry V, ii, 3) there is so accurate a picture of the characteristics of impending dissolution—picking at the sheets or floccitatio; the bloodless, pinched features, facies Hippocratica, and the delirium at the close of life that we may be certain that Shakespeare had witnessed not one but several deathbeds.

Sir John Falstaff is represented as dying in Mrs. Quickly's house in Eastcheap; and the account of the death of the fat knight is a remarkable piece of realism, yet not without its dash of humor, for it opens thus:

> Nay, sure, he's not in Hell; he's in Arthur's bosom, if ever man went to Arthur's bosom.

And the whole passage is exactly as a kindly but illiterate woman might have phrased it,—

> for after I saw him fumble with the sheets, and play with flowers and smile upon his fingers' ends, I knew there was but one way; for his nose was as sharp as a pen, and 'a babbled of green fields. "How, now, Sir John?" quoth I; "what man! be of good cheer." So 'a cried out—"God, God, God" three or four times; now I to comfort him, bid him 'a should not think of God; I hoped there was no need to trouble himself with any such thoughts yet; so 'a bade me lay more clothes on his feet, I put my hand into the bed, and felt them, and they were as cold as any stone; then I felt the knees and so upward, and all was as cold as any stone.

Surgery is concerned with wounds, with preventing them becoming poisoned, with the cicatrices left by them, and finally with the setting of bones that have been broken.

First of all, Shakespeare seems to have known of the surgeon's custom of comparing incisions to letters of the alphabet, for in "Antony and Cleopatra" (iv, 7) we read:

> I had a wound here that was like a T,
> But now 'tis made an H.

Of course he knew the domestic use of cobweb in causing blood to clot, for Bottom says ("A Midsummer Night's Dream," iii, 1), "Good master cobweb; if I cut my finger, I shall make bold with you."

A tourniquet is evidently alluded to in "Othello" (v, 1) where Iago calls for a garter to bind Cassio's leg just cut in two, and then exclaims, "O for a chair to bear him easily hence!" wherein once more we get evidences of intelligent "first aid."

The sepsis or festering of wounds was, until Lister's time, a perennial source of worry to the surgeon. In "Richard II" (v, 3) we read:

> This festered joint cut off, the rest rests sound;
> This let alone, will all the rest confound.

which as a surgical maxim could not be bettered to-day.

Shakespeare evidently understood that a wound could be infected, and yet no mischief be visible from the surface, for we have in "Hamlet" (iii, 4):

> It will but skin and film the ulcerous place,
> Whilst rank corruption, mining all within,
> Infects unseen.

Shakespeare seems to have known about one variety of infection, in the sense that moulds or fungi are to blame for it, for he says in "Hamlet" (ii, 4):

> . . . like a mildewed ear
> Blasting his wholesome brother.

At the same time we must not infer that the great dramatist was beyond his time in the matter of supposing that life could be engendered in decomposing bodies, for Hamlet says (ii, 2):—

> If the sun breeds maggots
> In a dead dog.

He understands that wounds must heal gradually, that what we call the "Vis medicatrix Naturae" has its own rate of working, for, says Iago ("Othello," ii, 3):

> How poor are they that have not patience,
> What wound did ever heal but by degrees?

As a bland application to a raw wound, we have white-of-egg recommended in "King Lear" (iii, 7), where a servant says:

> I'll fetch some flax and whites of eggs
> To apply to his bleeding face.

A wound having been healed, we call the scar "a cicatrix" and so did Shakespeare, for Volumnia in "Coriolanus" (ii, 1) says of Marcius:

> There will be large cicatrices to show the people
> When he shall stand for his place.

It is a familiar experience that old wounds from time to time give some uncomfortable sensations: it may be in allusion to this that Marcius (in "Coriolanus," i, 9) says:

> I have some wounds upon me, and they smart
> To hear themselves remembered.

Finally, it is well known that when two portions of a broken bone are united by what surgeons call "callus," and when this has become ossified, it is of a consistence much denser and therefore much stronger than either of the two portions of the bone that has been fractured: hence says the Archbishop of York in "Henry IV" (Part II, iv, 1):

> If we do now make our atonement well,
> Our peace will, like a broken bone united,
> Grow stronger for the breaking.

As might be expected, the most penetrating and remarkable pronouncements of Shakespeare are those which refer to the brain, the senses and the mind. In Shakespeare's day the various emotions were not all referred to states of excitement in regions of some gray matter of the brain and left there; they were distributed amongst the various viscera.

Even mental processes were not originally thought to have their exclusive seat in the brain, for the ancient Egyptians and later Aristotle believed the mind or soul to reside in the heart.

This view was held, for instance, by Vico in opposition to Descartes as late as the middle of the seventeenth century. Descartes himself placed the soul in the pineal body—a peculiarly unfortunate localization, seeing that the pineal body consists only of some atrophied cells surrounding a few crystals of mineral matter, "brain sand" or dust, and—

> Dust thou art, to dust returneth
> Was not spoken of the soul.

Even Van Helmont, who died in 1644, thought the soul was in the pit of the stomach, the pylorus. Certain very early Greek thinkers had indeed held that the soul was in the diaphragm, obviously because that great muscle of breathing is so accessible to emotional disturbances.

Although Galen regarded the brain as the true seat of the soul or intellect, that did not prevent the various internal organs from being thought of as related in some special way to the passions and emotions. Thus Pistol, in "The Merry Wives" (ii, 1), says that Falstaff loves Ford's wife "with liver burning hot."

The ascription of anger to the spleen has hardly departed from our everyday speech, as when we speak of a "fit of the spleen" or of a "splenetic" man as meaning an angry one.

If he followed any school of thought in respect of the brain versus other seats of the soul, Shakespeare followed that of Galen rather than Aristotle, for he makes Prince Henry in "King John" say of the King:

It is too late; the life of all his blood
Is touched corruptibly, and his pure brain
(Which some suppose the soul's frail dwelling-
place)
Doth, by the idle comments that it makes,
Foretell the ending of mortality.

In other words, he will not dogmatize about the brain as the seat of the soul, but he lets us understand that he knows of some who do so regard it. The delirium of the dying is clearly referred to in the last two lines.

Whatever Shakespeare did or did not believe about the cerebral seat of the soul, he was in no doubt at all that what nowadays we call hallucinations are very directly the products of disordered states of the brain.

The best known example of this is the "dagger of the mind," that elusive weapon which Macbeth saw but could not lay hold of ("Macbeth," ii, 1):

Is this a dagger which I see before me?
The handle towards my hand. Come! let me
clutch thee:
I have thee not and yet I see thee still,
Art thou not, fatal vision, sensible to feeling
As to sight? or art thou but
A dagger of the mind, a false creation
Proceeding from the heat-oppressed brain?
I see thee yet in form as palpable
As this which now I draw.

We have everything here: the visual hallucination of the dagger—a dagger of the mind—and it is all traced to Macbeth's disordered brain. Even the actual language can not be improved upon after 300 years: it is poetry scientifically justified.

Undoubtedly a visual hallucination is referred to by the queen in "Hamlet" (iii, 4) as the ghost is disappearing:

This is the very coinage of your brain,
This bodiless creation ecstasy
Is very cunning in.

Possibly one of the most remarkable passages of biological import in all the plays is one in "Love's Labour Lost" (iv, 2) where the schoolmaster, Holofernes, speaks of ideas in these words:

These are begot in the ventricle of memory, nourished in the womb of *pia mater*, and delivered upon the mellowing of occasion.

One of the interesting things about this statement is that it involves two technical terms of anatomy—a "ventricle of the brain" and the "pia mater," the latter, the anatomists' name for the soft, delicate membrane which, closely investing the gray matter of the hemispheres, conveys to it its nutrient blood-vessels.

"The ventricle of memory" was a phrase of the Arabian doctors of medicine, who taught that the brain possessed three cavities or ventricles in which resided the three mental faculties as follow—sensations in the anterior, imagination in the middle, and memory in the posterior one. Those views were adopted by the doctors of theology in the Middle Ages.

Against this particular belief Vesalius inveighed in his celebrated treatise, "De corporis humani fabrica," published in 1543. He wrote: "I wonder at what I read in the Scholastic theologians and the lay philosophers concerning the three ventricles with which they say the brain is supplied." Modern anatomists describe five ventricles.

Here Shakespeare adopts the terminology of the medieval writers; although it is by no means easy to see how he came to have access to it—the man who, when he died, left not a book, not even a second-hand one, behind him.

The phrase "nourished in the womb of pia mater" is, if anything, still more obscure; but this is not the only place in the plays where the membrane is mentioned.

The clown in "Twelfth Night" (i, 5) says:

Whose skull Jove cram with brains; for here
he comes,
One of thy kin has a most weak pia mater.

And once more it is referred to in "Troilus and Cressida" (ii, 1) where Thersites declares of Ajax, "His pia mater is not worth the ninth part of a sparrow." The pia mater does literally nourish the brain, and therefore, metaphorically, may be said to bring to development anything functionally related to the activity of the brain.

Whether Shakespeare really knew what the pia mater is can not now be determined, but assuming that ideas are "begot" in a cerebral ventricle (which they are not), it would be permissible to regard them as nourished by the membrane that nourishes the organ of thought. The completion of the analogy between giving birth to a child and bringing forth a thought is thus made possible.

Apropos of nourishment of the nervous system, there is an exceedingly striking statement in "Antony and Cleopatra" (iv, 8), where Antony says, "Yet we have a brain that nourishes our nerves."

We have only to translate this into modern physiology to perceive, what is literally true, that the cells of the brain are trophic for, that is, preside over the nourishment or vitality of the nerves. This is precisely what the brain does for the nerves; hence it has been called their "highest trophic realm." But in this sense it is impossible that Shakespeare could have known the facts; not until the microscope revealed that every nerve-fiber proceeds from a nerve-cell, and that, severed from the cell, the fiber dies, could we know all that is implied in this line.

It is, however, more probable that in this passage the poet is using the word "nerves" as meaning tendons in the original sense of nerves (neura).

There is another equally remarkable utterance regarding the nervous system, where Hamlet says (iii, 4):

> Sense, sure, you have,
> Else you could not have motion!

The principle that sensory impressions must precede motor in the education of the nervous system is now-a-days regarded as of immense practical importance. The fact could not possibly have been known to Shakespeare that those tracts in the central nervous system which subserve sensation are functionally developed a considerable time before those which subserve motion. We must regard this as one of those remarkable intuitions into scientific truth of which, at times, the poet's mind gives us such excellent examples.

Apropos of the development of the body, Shakespeare has not failed to note the "breaking" of the voice coincident with puberty in the male. The passage is in the "Merchant of Venice" (iii, 4) where Portia enumerates the various things she will do when she assumes the rôle of a young man; one of them is to

> speak between the change of man and boy,
> With a reed voice.

Physiologically allied to this subject is the effect of castration on the voice: this, as is well known, prevents the male vocal cords lengthening, so that the voice remains boyish and high pitched. Coriolanus (iii, 2) says:

> My throat of war be turn'd
> . . . into a pipe
> Small as a eunuch.

Shakespeare has some particularly penetrating remarks under the heading of the biology of the senses.

With regard to vision, the first phenomenon we might notice is that of the colored "after-image" (as it is technically called) associated with some degree of retinal fatigue. It is where Katherine in "The Taming of the Shrew" (iv, 5) says:

> Pardon, old father, my mistaking eyes,
> That have been so bedazzled with the sun,
> That everything I look on seemeth green.

This experience must be familiar to many; if the eyes are over-stimulated by exceedingly bright sunshine and one goes suddenly indoors, everything takes on a rather ghastly, pale green color.

The next example has to do with reflections of light from the cornea.

When you look closely into the eye of another person, you see a tiny image of yourself reflected from the convex mirror of the other eye; these images are known in biology as the "Purkinje-Sanson" images. They are clearly referred to in "Troilus and Cressida" (iii, 3), where Achilles says:

> . . . eye to eye opposed,
> Salutes each other with each other's form.

One of the most interesting conditions related to the sense of vision is the trance of Lady Macbeth. It is in the same scene as that in which we found the reference to the smell of blood (v, 1). Lady Macbeth is being watched by the doctor and by a lady-in-waiting, who remarks that she is "fast asleep." The doctor observes, "You see her eyes are open," to which the lady replies, "Ay, but their sense is shut."

Now first of all this is not natural sleep, for in that condition the eyelids are always closed; it is a state allied to somnambulism. In this state, the centers for vision in the brain are inhibited and functionless, so that although the eyes are open, the brain behind them is not perceiving anything, and therefore the individual is psychically blind. The state is akin to that of the mind-blindness induced in the hypnotic trance.

The unpleasant sensation of giddiness is noticed several times in Shakespeare's plays.

"Giddiness" is the name given to the subjective aspect of a disturbance in the sensory apparatus for the appreciation of one's orientation in space; it is the perceptual aspect of impending or actual overthrow of the equilibrium.

There are two varieties of giddiness or vertigo; one when the sufferer is unable to maintain his balance and, feeling faint, falls or tends to fall to the ground —a condition most usually the result of a diminution of the blood supply to the brain.

Since the whole brain—cerebrum and cerebellum—suffers from this anemia, the sensory centers for vision are rendered functionless, in consequence of which the sight fails or, as the patient puts it, "everything goes dark."

This is precisely what King Henry complains of (Henry IV, Part II, iv, 4), "And now my sight fails, and my brain is giddy." Let us note once again that Shakespeare correctly attributes the disability to the organ involved, the brain itself.

A very common cause of interference with the heart which produces anemia of the brain is the reception of bad news, as when King John says (iv, 2), "Thou hast made me giddy with these ill tidings."

The other variety of giddiness is that known as "rotational vertigo," the sort we experienced when, as children, we spun round our vertical axis, suddenly stopped and were for a minute or two exceedingly dizzy, unsteady and perhaps also slightly sick.

In rotational giddiness external objects seem to be moving round in the direction opposite to that towards which the person last turned. This apparent movement of external objects is exactly what is alluded to in "The Taming of the Shrew" (v, 2), "He that is giddy, thinks the world turns round." And lastly we know that if we are giddy, we can correct the giddiness and the illusory movement of the external world by turning round in the opposite direction.

This is precisely what Shakespeare refers to when he makes Benvolio in "Romeo and Juliet" (i, 2) say: "Turn giddy, and be holp by backward turning."

One of the most obvious functions of the brain is the power of speech, so that various imperfections of speech denote disease in one or other region of the organ of the mind.

Complete loss of speech is called aphasia; but, short of this, there is a functional disorder where words can still be spoken, *i.e.*, there is no paralysis, but in which they are all jumbled up so that they make no sense. The technical term for this is "paraphasia." In "A Mid-summer Night's Dream" (v, 1) we have a *perfect* description of paraphasia:

> His speech was like a tangled chain,
> Nothing impaired but all disordered.

I doubt whether any neurologist today could put it more pithily.

We may now close this study of biology in Shakespeare by considering a passage which is surely one of the most striking we have yet examined. It occurs in "Hamlet" (i, 5) that play, according to some critics, the profoundest of them all; it is where the ghost remarks:

> The glow-worm shows the matin to be near,
> And 'gins to pale his uneffectual fire.

Each of these two lines embodies a deep biological truth. First of all, why does the glow-worm show the matin to be near?

Because the feeble light of the glow-worm, in common with all other lights, begins to appear paler as the dawning daylight increases in intensity. The relatively feeble light emitted by the glow-worm can be seen easily in the dark because the retina, being, as it is called, "dark-adapted," responds readily to very slight illumination; as Pericles (ii, 3) says:

> like a glow-worm in the night
> The which hath fire in darkness, none in light.

In a strong light we do not perceive feeble lights; we do not see the stars in the daytime, although some of them are there; the moon in the daytime is just visible; in strong sunlight it is so difficult to perceive the flame of a fire that many people firmly believe that the sun is putting the fire out.

A candle, quite useful at night, scarcely adds anything to the illumination of a room in the daytime, as indeed Shakespeare says: "We waste our lights in vain, like lamps in day."

This is only an example of a particular case of a principle of wide-spread occurrence in living matter; namely, that a tissue, for instance the retina, having been stimulated and being in a state of activity, is insensitive to or irresponsive to further stimulation, an incapacity which has been called "functional" or "physiological inertia." If the retina is already stimulated by the daylight, it will not respond to (perceive) any much feebler light, such as that of a glow-worm.

Shakespeare, in fact, has said as much in "Romeo and Juliet" (i, 2), "One fire burns out another's burning."

But still more interesting is the use here of the word "uneffectual." Why is the light of the glow-worm an uneffectual fire? Because it is light without heat; a light that can not set fire to anything is indeed uneffectual. The light of a glow-worm is a perfectly cold light. When we pick up a glow-worm, it does not burn our fingers in the least. It has lately been ascertained that the light emitted by this creature (Lampyris) is due to an oxidative process known as chemi-luminescence whereby chemical energy is transformed into light without having to pass through the intermediate stage of heat. Man has not yet contrived to produce light without heat. Nature did so long, long ago when the light of the first glow-worms and the fire-flies twinkled in the primeval forest, when the first Noctiluca blazed their trail in the dark ocean, as the glistening wave struck the shore of that world millions of years ago.

Light without heat—without wasted heat—is what man ardently desires to have, and may some day discover, but up to now has not been able to produce.

The spectrum of this animal light also shows it to be devoid of vibrations both towards the red and towards the violet end: light such as this without the violet or the ultra-violet rays must be chemically inert, non-actinic and therefore once more "*un*effectual." We may well conclude with this splendid example of the amazing insight into living nature which our and the world's greatest poet possessed.

While one must deprecate anything like uncritical hero-worship, and while we should not yield to the not very uncommon temptation of reading into certain passages a meaning which it is quite impossible Shakespeare could ever have intended, yet we shall not greatly err if we admit that in the writings of this extraordinary man we find a wealth of observation in the realm of living things which is as extensive as it is penetrating and which is absolutely unparalleled in the literature of any other country.

The more we understand of what "the myriad-minded" Shakespeare has observed, the more we become lost in astonishment at the universality of his genius. Well did Pope say of him, "Shakespeare seems to have known the world by intuition, and to have looked through Nature at one glance."

THE MENTALITY OF PRIMATES

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In chapter three of "The Descent of Man," Charles Darwin writes, "My object in this chapter is to show that there is no fundamental difference between man and the higher mammals in their mental faculties." Essentially the same position is taken to-day by prominent sociologists and social psychologists. For example, Professor F. H. Hankins, comparing apes with men in his "An Introduction to the Study of Society" (New York, 1928) states, "In spite of his large brain, it cannot be said that man has any mental traits that are peculiar to him. His superiority is one of degree, and particularly in the higher degree of abstract thought, constructive imagination, analysis and generalization which he possesses." (p. 56). And, again (on p. 327): "All of these human superiorities are merely relative or differences of degree . . . . ."

The thesis of this paper is that, while there are many and impressive similarities between man and ape, there is one fundamental difference and this difference is one of kind, not of degree.

That apes do behave like human beings in many striking ways has been amply demonstrated by many students since Darwin. They give human-like expression to fear, rage, jealousy and love. They play games and jokes and even seem to express, quite eloquently at times, that highly prized virtue, gratitude. But, in spite of these many likenesses, there is one kind of behavior which is not manifested by any animal save man, and that is the use of symbols. And, I repeat, this difference is one of kind, not of degree. An animal is either capable of using symbols, or he is not; there are no intermediate stages.

One reason why discussions of mental differences between apes and man have been so muddled is because such hopelessly inadequate terms as ***reason, think, intelligence*** are used. The old problem, "Can dogs reason?" well illustrates the impassé into which such terminology leads us. One must use concepts that can be defined objectively. Human beings use symbols; apes do not. It remains for us, then, to define the concept *symbol* precisely and in objective terms.

TOOL-USING CAPACITY

Before discussing symbols, however, I should like to discuss another capacity which distinguishes primates from other animals, namely, the ability to use tools. I do not wish to go so far as to say that primates alone among animals use tools; I have heard of elephants wielding branches or sticks with their trunks. But certainly, the primates alone are distinguished for their ability to use tools and to build according to freely conceived plans. It is true that beavers, birds and wasps build. But they do not build according to freely conceived plans. The structures accomplished by these creatures are built according to plans which, specifically, constitute a part of their respective hereditary equipments. But apes[1] can build according to plans which are formulated to fit the situation of the moment. Thus an ape can build a structure of boxes and, with a tool which he has made by joining two sticks, knock a banana from the roof of his cage. The building activities of beavers, birds and wasps do not vary beyond narrow and rigid limits. But the ape can adapt his building activities to any situation; moreover, he can devise tools appropriate to the occasion.

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[1] I am referring chiefly to chimpanzees.

The difference between the tool-using and the building capacities of apes and other animals, then, lies in this: The behavior patterns of the non-primates are hereditary equipment of limited scope; the tool and building patterns of apes are not inherited, but are devised freely and for a great range of situations. The ape has the capacity to conceive of configurations and then to project them into materials, tools and objectives. He has the capacity to execute a series of acts implicity before he commences them overtly. Figuratively speaking, he rehearses in his mind the series of steps necessary to attain an objective before he makes a move. Then he proceeds to re-arrange his environment according to his plan. Thus the ape is a sub-lingual architect, or, even a dramatist. To say that he accomplishes his feats of building by trial and error is absurd. It is true that apes, like men, make trials and commit errors. But this does not mean that out of a mass of random movements a plan is born. The ape has the plan to begin with; the trials and errors are simply the incidents of his attempt to realize it in action. If this were not true the ape would be as likely to try to stand on his bowl of water as a packing-box to reach a banana, and as likely to try to poke it down with a gunny-sack as a stick.

CAPACITY TO USE SYMBOLS

We see, then, that primates differ from non-primates in the manufacture and use of tools and in the capacity to build. We now turn our attention to the capacity which distinguishes man from the other primates as well as from other animals, birds and insects. This is the capacity to use symbols. A symbol is a datum—a sound, an act or a material object—the meaning of which is arbitrarily assigned to it by those using the symbol. It differs in this respect from all other things. The meaning of anything is simply its position in its context. The meaning of a non-symbolic datum is determined by the properties which inhere in the datum itself and by the inherent properties of its context. Thus, the meaning of a canoe paddle, for example, is determined by the shape and properties of the wood and by its relation to a person, a canoe and the water. We are now in a position to distinguish between the symbolic behavior of human beings and the non-symbolic behavior of other animals.

Man, bird and beast communicate with sounds. But there is a fundamental difference between the vocal utterances of birds and beasts and the language of man. The meaning of infra-human cries is determined in the phonetic elements themselves and in the organisms of the creatures using them. But the meaning of a word, a phonetic element or compound, does not inhere in the sounds themselves; they are assigned to them by the users. Thus, the phonetic compound *si* has no meaning in itself; it may refer to the act of the eye, a great body of water, an affirmative reply or something else. The meaning has been assigned to this sound-compound in purely arbitrary fashion. But the cries of birds and animals are different. When a mother hen sounds a warning to her chicks, the meaning inheres in the sounds themselves and in the organisms of the chickens. The situation is slightly different when animals are taught to respond to words. Here the meaning of the sounds are not inherited by the animal, but nevertheless the meaning still inheres in the very sounds themselves. In short, cries are *signs* to birds and animals, not symbols, whether they be learned or inherited.

The same is true of acts and material objects. The meaning of an act or a material object to an infra-human creature is determined wholly by the properties of the act or the object itself and its relation to its context. But this is not always true where human beings are concerned. A stone is simply a stone to an animal or a bird, but to a man it may be the repository of a spirit. "Those aren't just sticks," a Pueblo Indian once told me very emphatically, when we were discussing prayer-sticks. And indeed they weren't. They looked like "just sticks" to the uninitiated, but they were sacred symbols to the Indian. Why? Because meaning had been created by the human organism and arbitrarily assigned to them.

And the same is true of many acts. Raising the right hand when taking an oath has no meaning whatsoever in the act itself; the meaning has been assigned to it.

THREE TYPES OF MENTAL BEHAVIOR

We are now in a position to outline three types of mind as manifested by organic life. And it is important to insist upon the qualitative differences between them. Due perhaps to the dominating influence of the idea of gradual evolution, many scholars have sought to interpret stages in mental development as differences of degrees. But certainly differences of kind are abundant enough in organic life: a quadruped either lays eggs or hatches them within the body. An animal breathes with gills or with lungs. And so, in the evolution of mind (which, after all, is simply a function of the organism, just as metabolism, respiration and reproduction are) we have definite breaks, or, more accurately, different types of organization of behavior which are qualitatively different from each other. These three types of mind, then, constitute stages of evolutionary development. Let us now turn to an examination of them.

THE UNILINEAR TYPE

This is the first stage. In its simplest form, the behavior pattern of the organism is a straight line; the animal approaches or withdraws from a stimulus. In more complex manifestations of this type of mind both stimuli and responses are multiplied, but the *quality of the behavior remains the same;* there is a unilinear relationship between organism and stimulus. Thus, when a dog is separated from a piece of meat by a fence and he runs away from the meat to go through a gate, he is simply responding successively to two different stimuli. This type of mind is the non-tool-using type and embraces all infra-primate creatures.

THE GEOMETRIC TYPE

This is the tool-using type of mind and is represented by primates only. Here we have a bi-linear configuration; that is, a relationship between primate and tool on the one hand, and a relationship between tool and objective on the other. Both exist and function simultaneously in the mind of the primate. This means that the primate can create configurations imaginatively, configurations which are in no way determined by heredity, and having created the configurations he can project them into acts and materials. In short, he can make tools and build. I call this type of mind the geometric type because it deals in geometric quantities—both plane and solid—lines, mass, and motion. None of the infra-primate creatures can behave in this manner.

THE ALGEBRAIC TYPE

This is the third and most recent stage in the evolution of mind. It is represented by man alone. It consists in the manipulation of symbols. In one respect it is like the geometric type: it consists of bi-linear configurations, the imaginative creation of configurations and their subsequent projection in sounds, acts and materials. But it differs in one respect from the geometric type, namely, in the sources of the meaning of their respective data. The meaning of data of the geometric type inheres in the properties of the data themselves: the meaning of a hammer or needle, a stick or a stone inheres in the object itself, just as the meaning of a right-angle or a circle inheres in the configuration. But the meaning of a symbol, like the meaning of an algebraic quantity, is assigned to it, in purely arbitrary fashion: X may equal ten horses or three quarts of milk or anything else. This type of mental organization, like the unilinear and the geometric, may be complicated by the multiplication of items involved in any given situation, until one manipulates symbols with symbols. In every-day language, we call this "abstract thinking," but the essential quality of the behavior remains the same. All linguistic thinking is abstraction.

Organic evolution has, then, produced three great types of mind, or mental organization, the first including all non-primate organisms, the second primates only, and the third man alone.

THE SIGNIFICANCE OF THE MENTAL CAPACITIES OF PRIMATES

Infra-primates perform; primates create as well. Beavers go on building dams generation after generation, ants repeat their social life with each succession of progeny. But with primates we get creative ability; the ape is the world's first artist. But the ape does not preserve his works, nor does he talk about them. Man does both. Civilization may be defined as the accumulated products of man's tool and symbol capacities; the former gives us the material side of civilization and the latter the intellectual and spiritual.

Postscript: Professor Edward Sapir, who kindly read this article in manuscript, suggests the terms *reactive, instrumental* and *symbolic* for the types of mind which I have called *unilinear, geometric* and *algebraic,* respectively. While I am preserving the original terms because of the emphasis which they place upon the configurative aspect of mind, I feel that Professor Sapir's terms should be placed at the disposal of the reader.—L. A. W.

SCIENCE SERVICE RADIO TALKS

PRESENTED OVER THE COLUMBIA BROADCASTING SYSTEM

THE PIPES OF PAN, OLD AND NEW[1]

By Dr. DAYTON C. MILLER
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FOR many years we have been studying the flute both historically and scientifically, and in doing this a collection of instruments illustrating all types of flutes has been acquired, now numbering more than a thousand specimens. Several of these have been selected for demonstration, representing the older types and also the most modern.

The flute is probably the first musical instrument used by man; it antedates history, and there are many legends and myths regarding the origin; "its infancy was passed in the twilight of fable." For our purposes the flute may be defined as any mouth-blown musical wind-instrument, in which the sound originates in the vibrations of the jet of air.

The earliest form of flute is a simple, natural piece of bamboo, a few inches long, which may be open throughout its length or may be closed at one end by the natural septum. When one blows across the open end of such a tube, a musical tone is produced. The edge of the tube may be blunt, or may be bevelled to a sharp edge. The primitive flutist soon discovered that tubes, or pipes, of different lengths give tones of different pitches, and so he tied several pipes together, side by side, and produced what is now called by the rather poetic name, the Pipes of Pan or Syrinx. This is probably the instrument referred to in Genesis, called in Hebrew, "Ugab," and translated in the English version as "organ." The poetic and romantic legends of ancient writers, and of modern artists, are fanciful, and need not be repeated now. The early Pan-pipes had a variable number of tubes—usually three, five or seven—tuned in a more or less capricious manner. This type of instrument is so simple in construction, so "cheap" to manufacture, and withal so musical in its effects, that it survives at the present time. Pan-pipes are in very common use by the natives of the islands of the sea, in Australia, Africa, and even for modern music they are used in the rural districts of central Europe and Italy. They are made in various sizes, corresponding to soprano, contralto, tenor, bass and sub-bass parts. The melody instruments may have as many as twenty-eight pipes, all tuned, varying in length from one and one half to ten inches. The instruments used for harmony usually have only one octave of tuned pipes, though other pipes may be added merely for appearance. The largest pipes may be three feet or even five feet in length. They are used in bands, consisting of from twenty to forty performers, and produce music which has the effect of a pipe organ. Such a band of twenty-two instruments is in my collection.

It was probably a very early discovery that a simple pipe, accidentally having a hole in the side of the tube, would give two tones, depending upon whether the hole is open or closed, and that the pitch of one of the tones depends upon the position of the hole. Thus there developed the very common type of wind-instrument consisting of a single tube, with a larger or smaller number of finger-holes, from which a scale of musical tones may be obtained. For simple melodic music, the number of holes required in the tube can be controlled by the fingers directly.

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[1] Primitive and modern flutes were played by Professor Miller during his talk to demonstrate their tonal qualities.

The Pan-pipes are sounded by simply blowing from the mouth across the open end of the pipe, and this method survives to-day in the flutes used in classical Japanese and Chinese music. It was another prehistoric discovery that the pipe may be sounded by blowing across a hole in the side of the tube. A third method was early developed, of providing the tube with an artificial mouth and lips arranged to direct a jet of air against the edge of the sound-hole, as in the common whistle.

These whistle flutes were very widely used from the twelfth to the eighteenth centuries. They were made in various sizes, from a few inches to eight feet or more in length, and were played in quartets and in larger choirs or bands, sometimes consisting of forty performers. This type of flute gives a very soft and simple tone, which may be described as mellow or sweet. The French call it the *Flûte douce*, and the Italians refer to it as the *Flauto Dolce,* and in general it is known as the flute-a-bec or the English flute, as distinguished from the German flute to be described later. In England this whistle type of flute is known as the Recorder.

Pepys' (1632–1703) Diary (1688) contains this entry:

> To Drumbleby's and there did talk a great deal about pipes, and did buy a recorder, which I do intend to learn to play on, the sound of it being of all sounds in the world most pleasing to me.

Shakespeare (1564–1616) introduces a band of Recorders in "Hamlet." Hamlet says:

> *Ham.* O, the recorders! Let me see one (turning to Guildenstern . . .) Will you play upon this pipe?
>
> *Guild.* My lord, I can not.
>
> *Ham.* I pray you.
>
> *Guild.* Believe me, I can not.
>
> *Ham.* I do beseech you.
>
> *Guild.* I know no touch of it, my lord.
>
> *Ham.* It is as easy as lying; govern these ventages with your fingers and thumb, give it breath with your mouth, and it will discourse most eloquent music. Look you, these are the stops.

The whistle flutes are restricted in range by the fact that the mouthpiece is simply a hole in a block of wood and is inflexible. Though the tone is sweet, it lacks variety, and soon palls on one. An instrument maker of London, about a hundred years ago, stimulated for a time the waning interest in the whistle type of flute by introducing the so-called English flageolet. He made instruments with two, and even with three, body-tubes attached to one head, so that one performer could play to a very limited degree music of two or three parts, simple duets and trios.

The type of flute blown crosswise directly from the mouth, over a hole in the side of the tube, has been known for two thousand years or more; the strength and quality of tone can be varied, and it is much more effective than flutes of the whistle type. However, it became a real musical instrument only about two hundred and fifty years ago, when the first key was added, so that a complete musical scale became possible. This kind of flute, known as the transverse or German flute, was held in very high esteem, being the most popular of all musical instruments for more than a century, beginning about 1700, when it became one of the principal instruments of the orchestra.

As music grew in complexity, additional holes in the sounding tubes were required and these were controlled by a key mechanism which sometimes is very complicated. Some flutes have as many as eighteen keys. There then developed the necessity for more accurate intonation and more uniform quality of tone; this led to the modern concert flute, which is usually constructed upon the acoustic and scientific principles developed about eighty years ago by Theobald Boehm, of Munich. The Boehm system flute probably approaches more nearly to the scientific ideal than any other musical instrument. It is *par excellence* the instrument for the enthusiastic lover of chamber music, while it retains its prominent position in the orchestra. The musical literature for the flute is greater than for any other solo instrument, excepting only the violin.

Flutes of different sizes and made of different materials give certain variations in tone quality which have not yet been fully appreciated. A richness of tone and an expressiveness have been acquired which are very pleasing. Unfortunately, the flute being the most agile of solo instruments, its ability to render rapid and difficult note-combinations is often exploited at the expense of its tonal characteristics.

LIQUID HELIUM

By Dr. H. C. DICKINSON

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THE production of liquid helium in the low temperature laboratory of the National Bureau of Standards in Washington affords an opportunity for a brief account of why the production of very low temperatures is important, what we may hope to accomplish with them, and perhaps for correcting some rather common misunderstandings about them. The name "fixed gas" was used at an early date to designate those gases which had never been obtained in liquid form. As time went on, the list of fixed gases continually became smaller as one after another was liquefied. Although chlorine and hydrochloric acid gas probably had been liquefied in 1804–6, it was not until in 1823, when the great pioneer scientist Michael Faraday accidentally liquefied chlorine gas, that a systematic study of the properties of gases was begun. Faraday promptly sensed the meaning of his discovery and thus began the studies which led to our present knowledge of gases. Faraday himself succeeded in producing liquid hydrogen sulphide, carbon dioxide, nitrous oxide (laughing gas), cyanogen, ammonia and hydrochloric acid gas.

This knowledge has made possible the entire industry supplying us with ice, ice cream and cold storage products, as well as our widely advertised gas and electric household refrigerators. In all these processes a gas is first compressed to the required pressure, then cooled until it becomes a liquid. This liquid is then allowed to evaporate at a lower pressure and thus produce cold.

Along about 1870, the list of known gases which had not been liquefied, and which were therefore called permanent gases, had been reduced to six. Early attempts to liquefy these more difficult gases such as air and hydrogen did not succeed because scientists did not know enough about the nature of the problem. It was well known that high pressures and low temperatures were needed to reduce gases to the liquid state, but other essentials were unknown, or at least unrecognized. Soon it was discovered, however, as we know to-day, that for each gas there is a "critical temperature," above which it can not be liquefied by any amount of pressure, but below which liquid will be formed if the pressure is high enough.

The more difficult gases, such as air, hydrogen and helium, have critical temperatures so low that they can not be reached by ordinary methods of refrigeration, so the gases do not liquefy when compressed. But a new fact about gases was discovered which met this difficulty. All gases when compressed and sufficiently cooled become colder when allowed to escape or expand through a nozzle or valve. This fact permits the regenerative refrigerating system which is now generally used to liquefy gases. The gas is first compressed to a high pressure, then cooled by any convenient means to as low a temperature as necessary, and allowed to expand through a small orifice. This cold gas is then used to further cool the compressed gas which follows it. The colder compressed gas is still further cooled on expansion and the process goes on, the temperature going lower and lower, until finally liquid is formed. Other methods also are used for making liquid air in large quantities, but this is the process by which the more difficult gases are liquefied.

Of the more difficult gases, air is easiest to liquefy. This liquid was first produced in measurable quantity in 1883. Hydrogen comes next and was first made in 1898; liquid helium, however, is a vastly different matter. It was first produced by Professor H. Kammerlingh Onnes at Leiden, Holland. This Dutch professor and scientist was the dean of all gas liquefiers. In the very early days, about 1890, he started the great low temperature or cryogenic laboratory at Leiden. For some forty years he devoted most of his great energy to researches in the field of very low temperatures. His descriptions of the difficulties and disappointments of his early work are intensely interesting. After years of careful study and preparation in which all the less difficult gases were liquefied many times the first liquid helium in the world was made in 1908. Professor Kammerlingh Onnes died in 1926, but Professors Keesom and de Haas, his successors, carry on the work. I saw and photographed a small tube of liquid helium in their laboratory last summer. It was surrounded first by a vessel of liquid hydrogen and outside that by a flask of liquid air.

Now helium itself is not a common substance. Most of the world's supply is found in the United States, and it is collected from a few natural gases which contain only a small percentage of helium. As you all know, it is the lightest gas except hydrogen. It is used for military airships because it is totally nonburnable and safe. It is by far the most difficult gas to liquefy because its boiling point, -452° F., is much lower than that of any other gas. The temperature means little, however, until one calculates that it is only about 7.6° F. above absolute zero, the lowest possible temperature. Compared with this the temperature of liquid hydrogen is 36.7° F. and that of liquid oxygen 162° F. above the absolute zero. The liquid helium produced at the Bureau of Standards recently was further cooled to 3.4° F. absolute by lowering the pressure with a vacuum pump. The very lowest temperature ever produced was reached in a similar way after months of preparation by Professor Kemmerlingh Onnes and was about 1.6° F. absolute.

The process of liquefying helium is a complicated one on which the staff of the bureau has been working for many months. First cold brine is used to cool carbon dioxide and to precool air. The carbon dioxide is then used to cool and liquefy air, the liquid air is then further cooled by reducing the pressure and used to cool and liquefy hydrogen. The pressure on the liquid hydrogen is then lowered to a point where the hydrogen begins to freeze. This very cold hydrogen is then used to cool the compressed helium which on expanding further cools itself and finally becomes liquid at a temperature of 7.6° F. absolute.

From 1908 to 1923 liquid helium was available only at the University of Leiden. In 1923 it was liquefied at the University of Toronto, Canada, by Professor McLennan; in 1925 at the Physikalische Technische Reichsanstalt, Berlin, Germany, by Professor Dr. Meissner; at the University of Berlin in 1930 by Professor Ruhemann; and finally at the Bureau of Standards on April 3 by Dr. F. G. Brickwedde and his staff, Mr. Cook, engineer, Mr. Scott, junior physicist, Mr. Smoot, mechanician, and other assistants.

But why produce liquid helium? In the first place, we have at present an international temperature scale which is uniform throughout the world, but has not been extended to the lowest temperatures, and liquid helium will assist in making this extension possible.

Beyond this, however, you have all heard much of Professor Einstein and perhaps something of other scientists now working on the very difficult subject of the constitution of matter and of the universe. This modern attempt to push back the confines of human knowledge has already vitally affected the industries and our every day life through such things as the radio, x-rays, television and numerous others. However, some of the most difficult questions raised by these researches can be answered only by resort to the study of phenomena at the temperatures made possible by liquid helium.

There is now available at the Bureau of Standards in Washington a laboratory where some of those interested in such problems as are here mentioned can find the answers.

DID PREHISTORIC MEN LIVE IN THE MIDDLE WEST?

By Dr. M. M. LEIGHTON

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JUST a few weeks ago, a very important and a very unusual conference was held in Chicago, under the auspices of the National Research Council. This conference brought together a distinguished group of highway and construction engineers, railroad officials, state geologists, noted anthropologists and heads of sand and gravel companies, from all parts of the Middle West.

What do you think they talked about? Was it engineering problems? The best ways to build railroads, highways, buildings? Not at all! They talked about prehistoric man and what should be done in an effort to discover either his remains or some evidence of his having lived in this region thousands and thousands of years ago. Recent scientific discoveries, in Europe and Asia especially, have proved definitely that man's life on the earth dates back as much as a *million* years, but not on this continent.

In the past, possible discoveries have been made in this country—discoveries that might have furnished scientists with the proof that they needed to settle the question, but the finds were rendered valueless by their removal when found. Such discoveries should not even be touched until trained scientists have given them their study and formed professional opinions on the spot.

Sometime, somewhere in the Middle West, some one is apt to make an important discovery during the course of some commercial excavation, and the men who attended the conference in Chicago want that discovery to be made under conditions that will give it the scientific endorsement that it will certainly deserve.

During recent years, the search for the bones of our earliest ancestors has caught the popular interest, and most of us read with enthusiasm the newspaper and magazine accounts of the ambitious expeditions that are led by Roy Chapman Andrews, and other famous explorers.

You will recall that most of these

"hunters after truth" conduct their searches in southern Europe, or in western Asia and Asia Minor, or in northern Africa. There is a reason for this. Anthropologists are generally agreed that the first humans lifted their eyes from the ground and stood erect beneath the clear skies of the Mediterranean region. It is practically certain that mankind's birthplace was within 2,000 miles of the plains of Syria, which as you know lie at the eastern end of the Mediterranean Sea. As I say, authorities agree on that point, but there is wide difference of opinion among them in regard to the direction from Syria of that all-important locality. Each expedition is based on careful research and well-supported opinions whether it plunges into the African wastes, treks across the desolate plateaus of southwestern Asia, labors under the scorching sun of Arabia, Mesopotomia and Persia, or carries on its investigations under more pleasant conditions in Europe. No one can yet say that *his* idea has proved to be the correct one. But hope persists eternal.

From this native district, wherever it may have been, the first race of humans spread slowly across the face of the earth, along four main lines of migration. One group apparently struck out to the southeast and developed into the Australoid race. Another group migrated to the south—the ancestors of the Negroid race. A third group, fortunately, decided to shift to the northwest and in time developed into the Caucasian or white race. The fourth group, for some reason or other, was attracted by the ever-receding horizon to the northeast, and they moved in that direction, to become the ancestors of the Mongoloid race.

As successive generations of these groups migrated farther and farther from the unknown central locality they became more and more affected by varying conditions of climate, natural resources, food supplies and living habits, so that in time each group became differentiated from the others in respect to color of skin, features of the face, stature, relative mentality and cultural achievements. Before long, the four major races of mankind were very clearly and distinctly demarked.

Now to get back to the question of whether or not prehistoric man ever lived in the Middle West. All the evidence seems to point to the fact that man very probably did not originate in the new world, but that he migrated from Asia, by way of Siberia and Alaska. But when did this migration take place, and to what human level had these first Americans developed when they first set foot upon the North American mainland?

We know that prehistoric men lived in western Europe and in eastern Asia long before the last epoch of the Great Ice Age. Since the climatic changes which caused the ice invasions were world-wide in their influence, and the ice invasions took place in North America and Europe at the same time, the glacial deposits and the human records that they may contain both in Europe and America, can be correlated on a fairly exact time basis. Why shouldn't we find evidence of glacial man in this country? Surely, the American Indians, the Mayas, the Aztecs and the Incas were not created as the white man found them. They must have developed from some common ancestral form, and that development must have been going on for thousands of years before the white man arrived, so great were the racial and even tribal differences by that time.

Did the ancestors of these native Americans get here before the last great ice invasion; did they arrive during the time of the ice invasion itself; or did they get here after the great glaciers had melted away? Only time and careful search of the various glacial deposits can clear up the mystery. These deposits cover most of the surface of Wisconsin, Minnesota, Michigan, Illinois, Indiana, Ohio, northern Missouri, Iowa, northeastern Kansas, eastern Nebraska, and areas to the north, northwest, and northeast.

We are entirely justified in projecting the possible existence of the first Americans back as far as the closing stages of the last glacial epoch, and to say that they may have witnessed the spectacle of a great ice sheet. If that was the case, some proof of their existence at that time should be preserved in the glacial drift deposits of the Middle West. There are some people who believe that the extinct race which we refer to as the Mound Builders were a very ancient race of people. This group flourished in the Middle West possibly as much as 5,000 years ago, probably no earlier. They were, beyond question, descended from more primitive stock, which may or may not have preceded them in this region. We must look back thousands of years beyond the first days of the Mound Builders, if we are to solve the mystery of the original Americans.

How about the cliff-dwellers of the Southwest? Will their records solve the riddle? No, I am afraid not. Old as are the ruins of their once populous communities, they date back no earlier than 500 or 600 to 2,000 or 2,500 B. C.—only a fraction of the time that has elapsed since the Great Ice Age. Then, too, we must take into account the fact that the skulls of both the Mound Builders and the early cliff-dwellers show that these people belonged to the species *homo sapiens,* as does modern man himself. They were distinctly not members of an earlier, more primitive prehistoric race such as the early Ice Age men belonged to. Every now and then some one finds some fossils in North or South America, and advertises them as the remains of an ancestral man or even anthropoid. But in each case, so far, their claims have been shown to be false or insecurely founded or debatable, and the hunt is still as hot as ever.

In the last analysis, the whole question of the antiquity of man in America must be answered by an appeal to geology. With what geologic formations are the oldest remains of man or man-made implements associated?

So far, no positive evidence has been unearthed to show that humans existed hereabouts during Glacial times. Any relics, in order to be satisfactorily dated, must be found in association with glacial deposits or related deposits. If we do find them below glacial deposits that have not been disturbed since they were laid down, then we can be sure that the relics are older than the materials that have buried them. It is equally safe to apply the same line of reasoning to the explanation of any discovery showing that man lived here during the time that the glacial materials were being deposited.

We can be greatly encouraged by some findings which seem to be almost authoritative, as, for example, the recent discovery in Oklahoma of a man-made flint spear point, which was found lying with the bones of primitive elephants, horses, camels and smaller animals—all of which creatures are believed to have become extinct on this continent during the Great Ice Age, or shortly after its close. We can say definitely that some form of mankind lived here before the extinction of these forms of animal life which were abundant during the Ice Age, but which are not known to have lived very long beyond that period, and there is reason for thinking that migrants of the Mongolian race may have crossed the Bering Strait before the close of the Glacial Period, long enough ago for them to populate extensively the western hemisphere before Columbian days.

HOW A SPIDER CAUGHT AND DINED UPON A SIX-INCH SNAKE

By L. F. PINKUS

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If one were to study the menus of various centuries and races one would obtain an extremely interesting result. It was not only Lucius Lucinus Lucullus, who died 57 B. C., that devised splendid meals. Even some members of our animal world seem to have quite a Lucullan appetite at times. This part of natural history has interested quite a number of our great naturalists. Darwin, Fabre and others owe some of their intimate knowledge to their great inquisitiveness concerning the dinner plates of our little foes and friends.

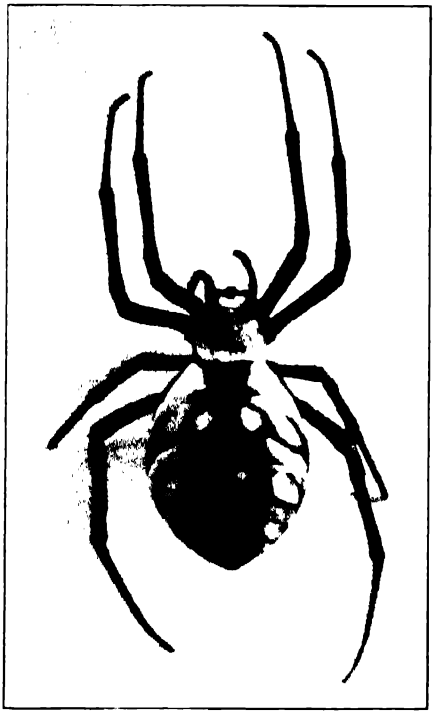
I myself recently had the rare opportunity of getting a glimpse of an unusual bill of fare of our well-known yellow-black garden spider, *Miranda aurantia.* Lucas, in 1833, according to Anthony Comstock's "Spider Book," gave this beautiful creature the name Miranda from the Latin word meaning "to gaze upon," "to wonder," and *aurantia* meaning "golden" (Fig. 1).

That spiders like what seems to us unusual foods for them has been attested by various observers. In his "American Spiders and their Spinning-work" (1889), Henry McCook relates a story of a farmer who found a bird, the kingster, entangled in the snare of such a spider. Another case occurred near Philadelphia, where a David DeHaven found a humming bird being captured in a spider's web. The observer watched the process of swathing the poor victim until it was completely wrapped around, when he slew the spider and rescued the bird, too late, however, for it was quite dead. Several instances of spiders as fishermen and hunters are related by Professor E. W. Gudger in *Natural History,* Vol. xxv, No. 3, from which work I quote the following account of S. Cummings:

> On the evening of the 13th inst. a gentleman in this village [Batavia, N. Y.] found in his wine cellar a *live striped snake,* nine inches long, suspended between two shelves by the tail, by spiders' web. The snake hung so that his head could not reach the shelf below him by about an inch; and several large spiders were then upon him, sucking his juices. The shelves were about two feet apart; and the lower one was just below the bottom of a cellar window through which the snake probably passed into it. From the shelf above it there was a web in the shape of an inverted cone, eight or ten inches in diameter at the top and concentrated to a focus, about six or eight inches from the under side of this shelf. From this focus there was a strong cord made of the multiplied threads of the spiders' web, apparently as large as common sewing silk; and by this cord the snake was suspended.
>
> Upon a critical examination through a magnifying glass, the following curious facts appeared. The mouth of the snake was fast tied up, by a great number of threads wound around it so tight that he could not run out his tongue. His tail was tied in a knot, so as to leave a small loop or ring through which the cord was fastened; and the end of the tail, above the loop, to the length of something over half an inch, was lashed fast to the cord to keep it from slipping. As the snake hung, the length of the cord from his tail to the focus to which it was fastened was about six inches; and a little above the tail there was observed a round ball about the size of a pea. Upon inspection this appeared to be a green fly, around which the cord had been wound as the windlass with which the snake had been hauled up; and a great number of threads were fastened to the cord above, and to the rolling side of this ball to keep it from unwinding and letting the snake down. The cord, therefore, must have been extended from the focus of the web to the shelf below, where the snake was lying when first captured; and, being made fast to the loop in his tail, the fly was carried and fastened about midway, to the side of the cord. And then, by

rolling this fly over and over, it wound the cord around it, both from above and below, until the snake was raised to the proper height and then was fastened as before mentioned (Fig. 2).

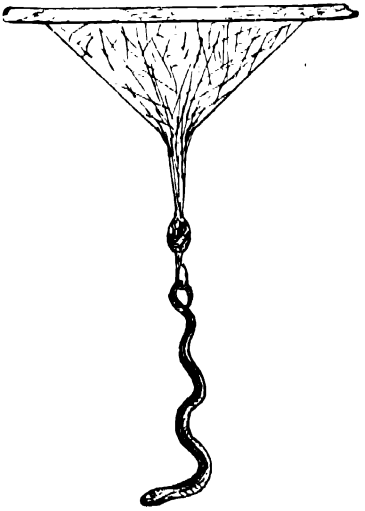
In this situation the suffering snake hung, alive, and furnished a continued feast for several large spiders, until Saturday forenoon, the 16th, when some persons, by playing with him broke the web above the focus so as to let part of his body rest upon the shelf below. In this situation he lingered, the spiders taking no notice of him, until Thursday last, eight days after he was discovered, when some large ants were found devouring his dead body.



—*Photographed from life by L. F. Pinkus*

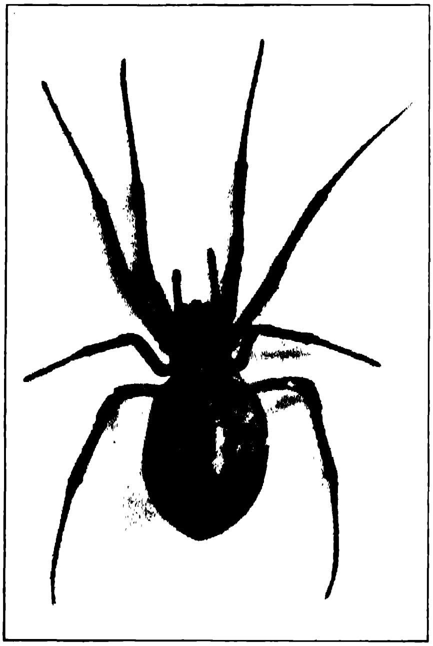
FIG. 1. A LIVE FEMALE *MIRANDA AURANTIA*

THE "WONDERFUL GOLDEN" SPIDER, SEEN FROM ABOVE.



—*After McCook, from Beecher*

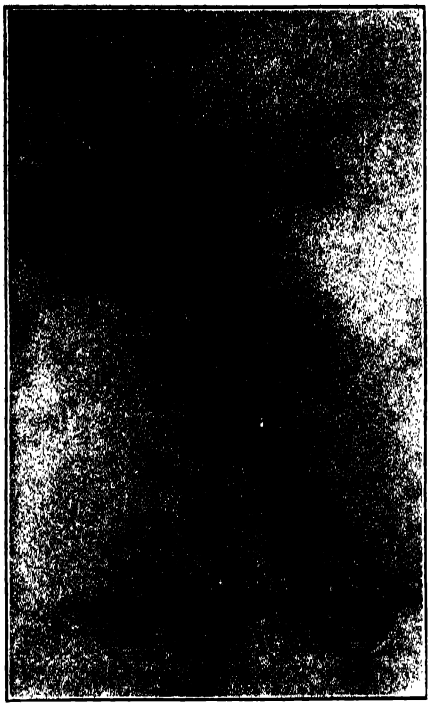
FIG. 2. A SNAKE SNARED IN A SPIDER'S WEB.



—*Photographed from life by L. F. Pinkus*

FIG. 3. VENTRAL VIEW OF THE "WONDERFUL GOLDEN" SPIDER.

A very similar account, differing only in details, was given in the same journal by D. Lyman Beecher. Dr. Asa Fitch has likewise published an account of such a phenomenon in the *Annual of Scientific Discovery*, 1862, pp. 334–35. In this case, however, it was a question of but one spider, not of several as was the case in the two preceding experiences, suspending the snake by the head, not by the tail. The odd thing about these observations was the slow torture



—*Photograph of a preserved specimen by L. F. Pinkus*

FIG. 4. A YOUNG 6-INCH SNAKE, *TROIDOCLONIUM LINEATUM.*

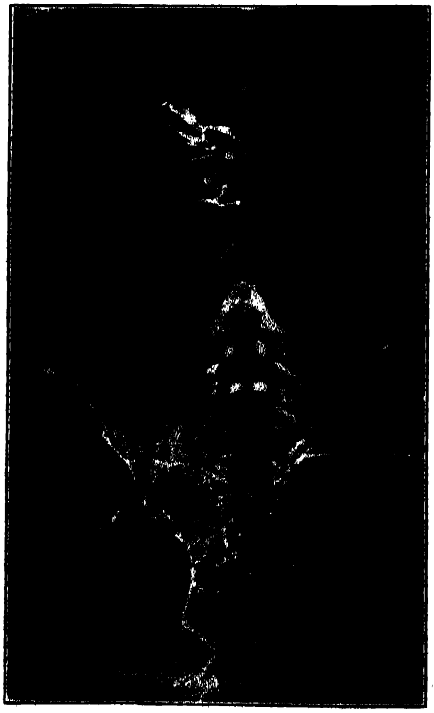
lasting over a period of days. Just what spiders were responsible is not known.

Let me now add my little story of how the Miranda, the "wonderful" spider, caught and dined on a snake (Fig. 3).

In order to make the instruction of natural history for the city pupils as vivid as possible I keep a few live pets of various kinds in the laboratory. The boys also occasionally bring in specimens. One day, a pupil brought in a lined-snake (*Tropidoclonium lineatum*), a mother with a brood of young ones. After having proudly exhibited his trophy for a few days in a cage I had provided, he took his booty home, but overlooked a little snake about six inches long, which he unwittingly left in the cage (Fig. 4). The following day I used this cage as a home for a full-grown female "*Miranda aurantia.*" It was a few hours later that we noticed that the place was already occupied. Rather strange room-mates, the spider and the snake, although both are despised members of the animal world. And here the strange drama begins.

The yellow-black lady made herself quite at home and during the first night of her stay manufactured one of her beautiful art pieces, placing her web diagonally across the cage (Fig. 5). The two occupants lived together in peace for a few days in the same quarters, apparently not minding each other, and were fed by the pupils or by myself.

One fine morning I entered the laboratory and found the members of the class very excited. Stepping up to the cage where they had gathered, I noticed the snake lying on the floor of the cage quite changed, as one may see from the accompanying picture (Fig. 6). The



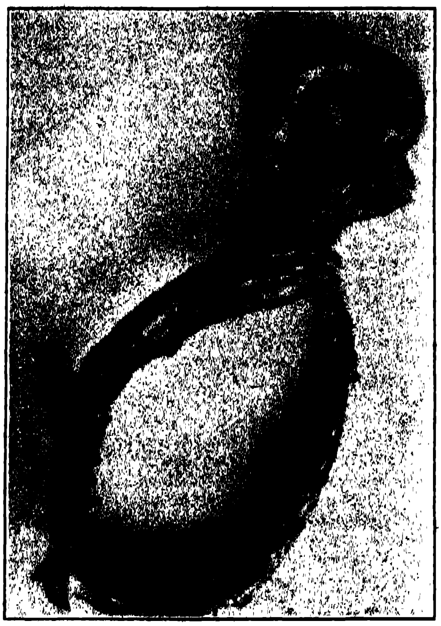
—*Photograph by L. F. Pinkus*

FIG. 5. THE "WONDERFUL GOLDEN" SPIDER IN THE CENTER OF HER WEB.

spider was sitting in her web, which was as lovely as ever. Immediately thirty youngsters bombarded me with questions; for the excitement was intense as the numerous conjectures as to what had happened were being hotly defended and as ardently denied by the youthful observers. The questions hurled at me, I could not fully answer at the time.

After a while one of the laboratory attendants gave us the explanation. The previous day after we had left the room, he happened to come to the place and was not a little surprised to find that the snake was caught with the tail-end in the spider web. The astonishing thing was that the reptile, in spite of frantic efforts, could not free itself from the web. The busy arachne wrapped her ribbon-like threads around the snake more and more. She seemed to make use of the situation to her advantage because while the snake was doubling up, the spider tied the victim up in such a way that the snake could not straighten out again. After a while the snake seemed to be overcome by the poison from the bites of the spider. Soon after that, the spider hoisted her prey to the center of the web and dined on the snake in her fashion. When she had finished she cast out the remains, leaving us the specimen in the shape as the picture illustrates (Fig. 6). Then she rebuilt her web.

It will be seen that the entire process of enveloping the snake, and particularly of extracting the juices, lasted but a short time. This is at variance with the accounts mentioned in the early part of this paper, but is entirely in accord with both the observations and the experiments made by Dr. Ernest Warren, Director of the Natal Museum. He found that the South African spider he dealt with had captured a lizard and had eaten practically all of it within two and a half hours. In describing the feeding process and the action of the digestive fluid upon the flesh of the lizard, he says, "In the course of an hour the whole body of the lizard, with head, limbs and tail, had been kneaded into a round, wet mass permeated with the digestive fluid and continuously being chewed by the chelicerae." "After a period of about two and a half hours the body (about 1¾ inch long) of the lizard had been reduced to a small, blackish, rounded and somewhat dry mass about ¼ inch in diameter. This mass the spider allowed to drop to the ground."



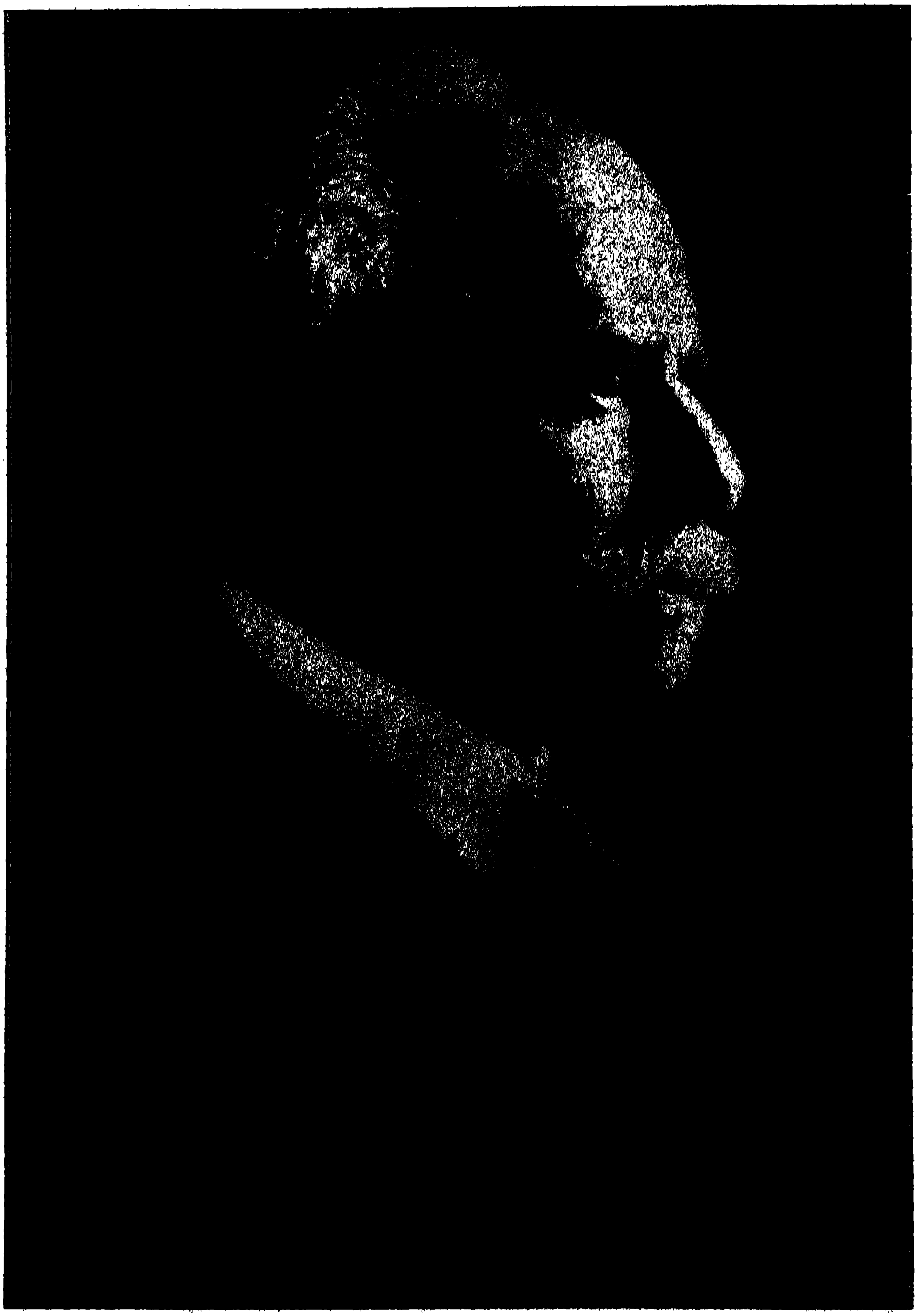
—Photograph by L. F. Pinkus

FIG. 6. THE REMAINS OF THE LITTLE SNAKE

AFTER THE SPIDER HAD DINED ON IT.

One wonders if the poet Southey was aware of such strange happenings when he addressed the following lines "To a Spider":

For, Spider, thou art like the poet poor,
  Whom thou hast help'd in song.
Both busily, our needful food to win,
  We work, as Nature taught, with ceaseless pains,
    Thy bowels thou dost spin,
    I spin my brain.



DR. FRANZ BOAS

PROFESSOR OF ANTHROPOLOGY, COLUMBIA UNIVERSITY; PRESIDENT OF THE AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE

THE PROGRESS OF SCIENCE

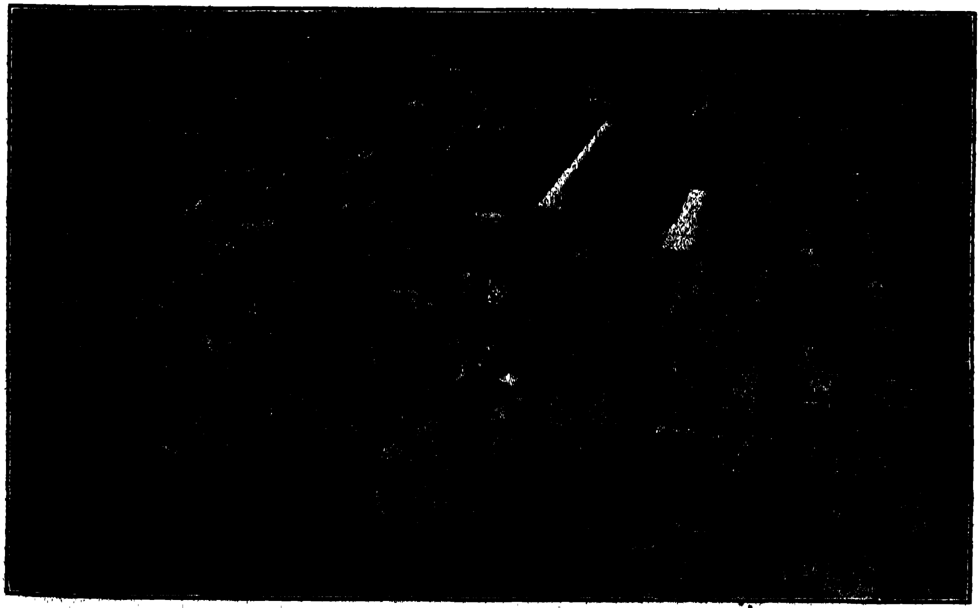
THE NEW ORLEANS MEETING OF THE AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE

After twenty-five years the American Association for the Advancement of Science returns to New Orleans for its winter meeting, to be held from December 28 through January 2. Once again Tulane University is the host institution.

New Orleans, with its mild winter—like a northern Indian summer—will, it is hoped, enable delegates to appreciate the wealth of interesting setting in this unique area of the United States.

Though it has grown to be a cosmopolitan city of half a million, New Orleans still offers a startling contrast between a modern commercial metropolis and a historical section whose French and Italian inhabitants suggest Europe rather than twentieth century America. The Vieux Carré, which is to be the ground for sightseeing trips by all sections of the association, has many buildings still standing which date from the days of the French and Spanish occupations.

Professional historians and amateur sightseers alike will visit such places as the Cabildo, or government house of the Spanish era, where the transfer of the Louisiana Purchase to the United States by France took place; the Old Absinthe House, where the French pirates of the Gulf plotted; the St. Louis Cathedral, one of the oldest religious edifices in North America; the antique stores of the Rue Royale. Just outside the city is the battlefield of Chalmette, scene of the Battle of New Orleans, in the War of 1812, the colonial mansion used as a headquarters by General Andrew Jackson is preserved as a memorial. Accessible by motor bus are the adjoining country districts, where archaic French is still heard as often as English, and



TULANE UNIVERSITY AND ITS SURROUNDINGS

DR. J. H. MOORE
ASTRONOMER, LICK OBSERVATORY; CHAIRMAN OF THE SECTION OF ASTRONOMY

DR. BERGEN DAVIS
PROFESSOR OF PHYSICS, COLUMBIA UNIVERSITY; CHAIRMAN OF THE SECTION OF PHYSICS

DR. E. R. HEDRICK
PROFESSOR OF MATHEMATICS, UNIVERSITY OF CALIFORNIA AT LOS ANGELES; CHAIRMAN OF THE SECTION OF MATHEMATICS

DR. C. A. BROWNE
CHIEF OF THE BUREAU OF CHEMISTRY, U. S. DEPARTMENT OF AGRICULTURE; CHAIRMAN OF THE SECTION OF CHEMISTRY

DR. DOUGLAS JOHNSON

Professor of physiography, Columbia University; Chairman of the Section of Geology and Geography

DR. ROBERT HEGNER

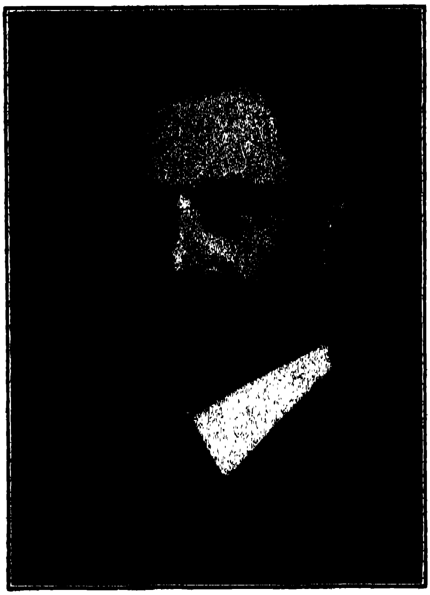
Professor of protozoology, Johns Hopkins University; Chairman of the Section of Zoological Sciences

DR. E. D. MERRILL

Director of the New York Botanical Garden; Chairman for the Botanical Sciences

DR. WILLIAM K. GREGORY

The American Museum and Columbia University; Chairman for Anthropology

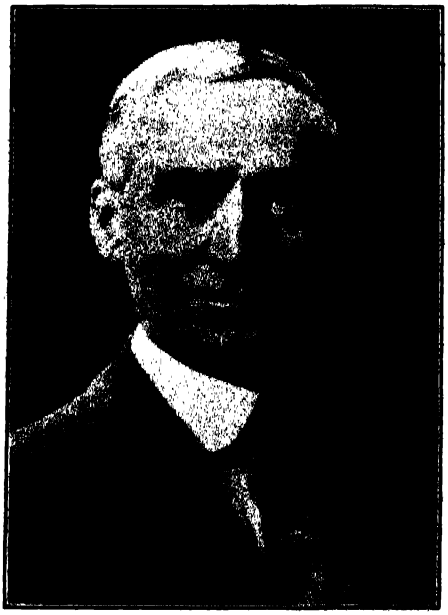


DR. HERBERT S. LANGFELD

PROFESSOR OF PSYCHOLOGY, PRINCETON UNIVERSITY; CHAIRMAN OF THE SECTION OF PSYCHOLOGY

DR. WILLIAM B. MUNRO

PROFESSOR OF HISTORY AND GOVERNMENT, CALIFORNIA INSTITUTE OF TECHNOLOGY; CHAIRMAN FOR HISTORICAL AND PHILOLOGICAL SCIENCES

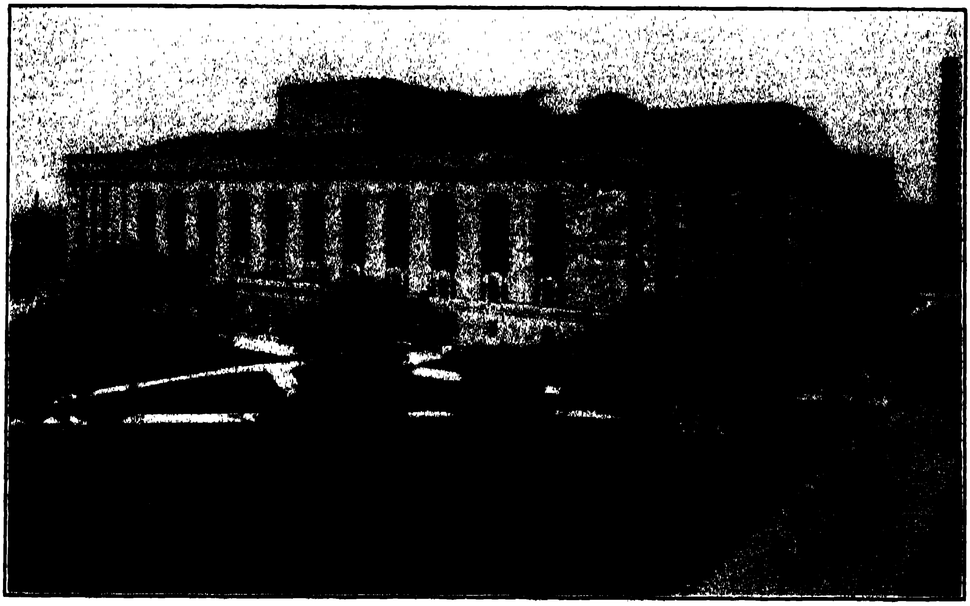


DR. DEXTER S. KIMBALL

DEAN OF THE COLLEGE OF ENGINEERING, CORNELL UNIVERSITY; CHAIRMAN OF THE SECTION OF ENGINEERING

DR. HOWARD T. KARSNER

PROFESSOR OF PATHOLOGY, WESTERN RESERVE UNIVERSITY SCHOOL OF MEDICINE; CHAIRMAN OF THE SECTION OF MEDICAL SCIENCES



THE MUNICIPAL AUDITORIUM

HEADQUARTERS OF THE GENERAL LECTURES AND THE RESEARCH EXHIBITS

it is here that are found those descendants of the Acadians whose story was so eloquently told in Longfellow's "Evangeline."

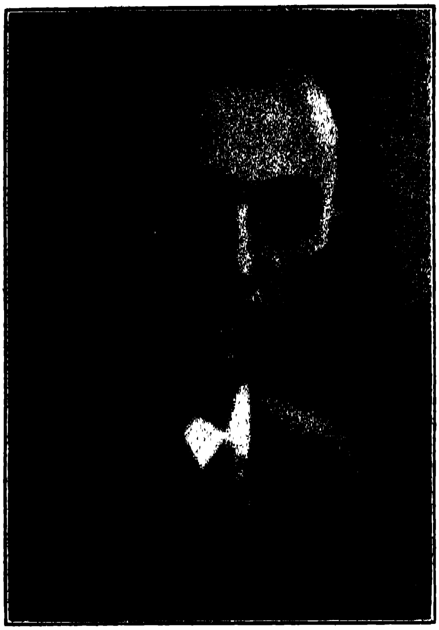
Contrasting with such an atmosphere is the new $2,000,000 municipal auditorium which the city has graciously placed at the disposal of the association for its larger gatherings. Contrasting, too, are the city's 1,200 factories and the miles of shipping—New Orleans has one of the largest water-fronts in the world—which bear witness to its position as the gateway to Latin America.

The 92-acre campus on which are located the main departments of Tulane University is in the heart of New Orleans' most exclusive residential section, facing the beautiful Audubon Park. Thanks to the able administration of President Albert B. Dinwiddie, the host institution offers the visiting scientists a whole series of new facilities which will be of great value in carrying on the work of the convention. The most important of these is the new Hutchinson Memorial Building, used for the instruction of third and fourth year students in the college that has made Tulane nationally known in the field of medical science. It is located on Tulane Avenue, opposite the great Charity Hospital, the facilities of which are used in instruction. This building with equipment cost approximately $1,250,000 and is in every way one of the most modern units in the United States for the study of medicine.

Since much of the time of the engineering section is to be given to Mississippi River flood control problems, the new laboratory equipment in hydraulics which is one of the latest additions to the college of engineering will be of especial importance. This is located in the old Engineering Building, which also houses the school of civil engineering. The new Science Building, housing the Museum of Middle American Research, will also be of special interest. It is to be the scene of several meetings of the archeological section. Another group of buildings which is to be utilized is the H. Sophie

PROFESSOR C. G. WILLIAMS

Director of the Ohio Agricultural Experiment Station; Chairman for Agriculture



DR. ERNEST HORN

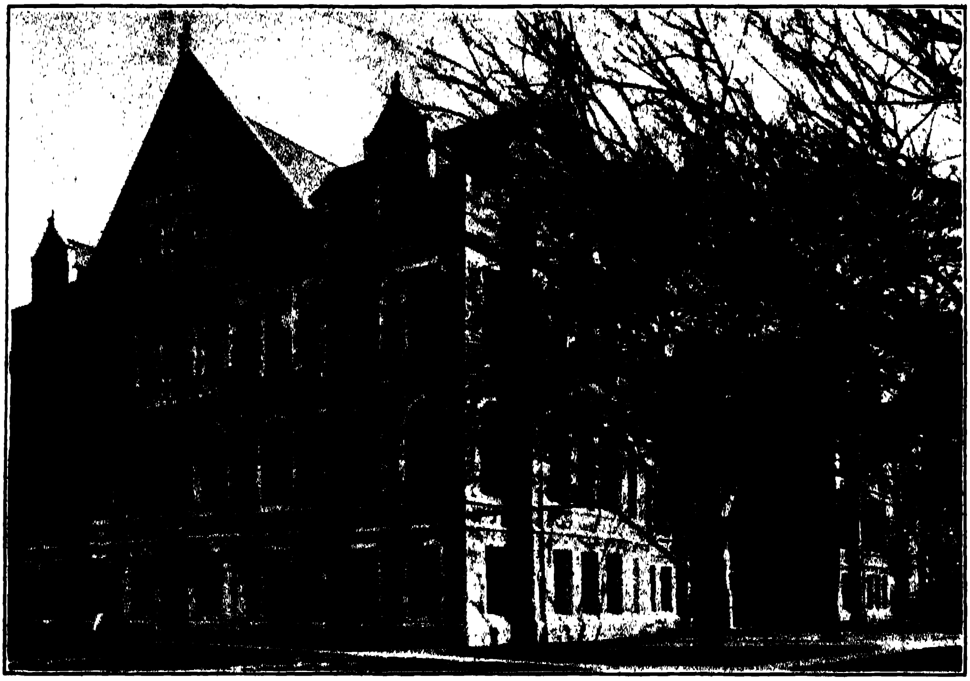
Professor of education, University of Iowa; Chairman of the Section of Education

DR. A. B. DINWIDDIE

President of Tulane University; Honorary Chairman for the New Orleans Meeting

DR. D. S. ELLIOTT

Professor of physics, Tulane University; Chairman for the New Orleans Meeting



THE SCIENCE BUILDING

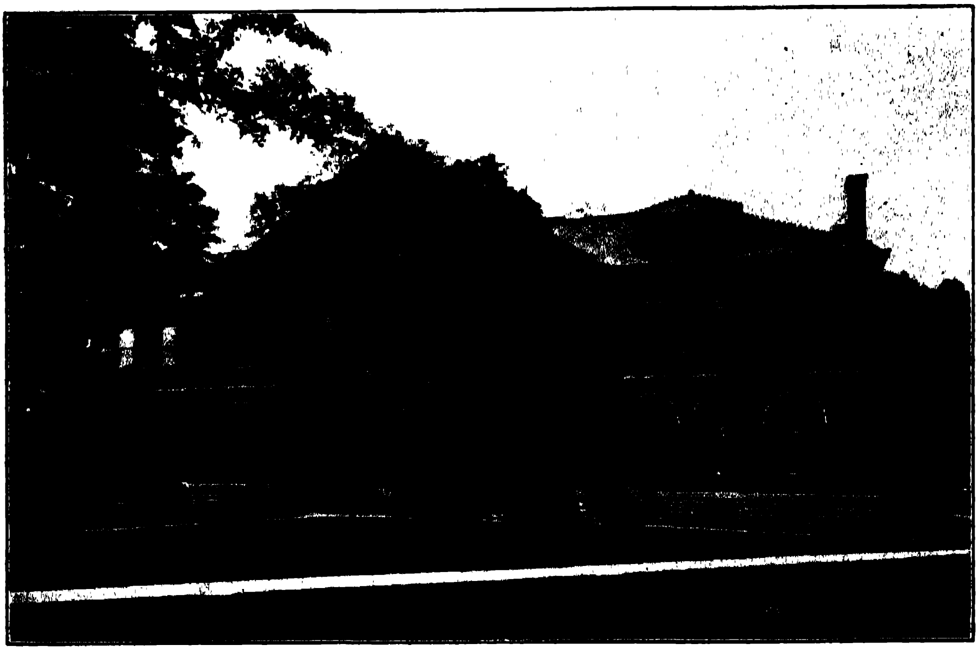
Newcomb College for Women, a division of the university which has its own campus. The dormitory buildings and Dixon Hall, the auditorium of Newcomb College, are to be used by the mathematical section.

In accordance with the objectives of the American Association for the Advancement of Science, the program will carry out the dual function of bringing together scientific men and their researches on the one hand and at the same time of promoting a better appreciation of scientific aims and accomplishments by the public.

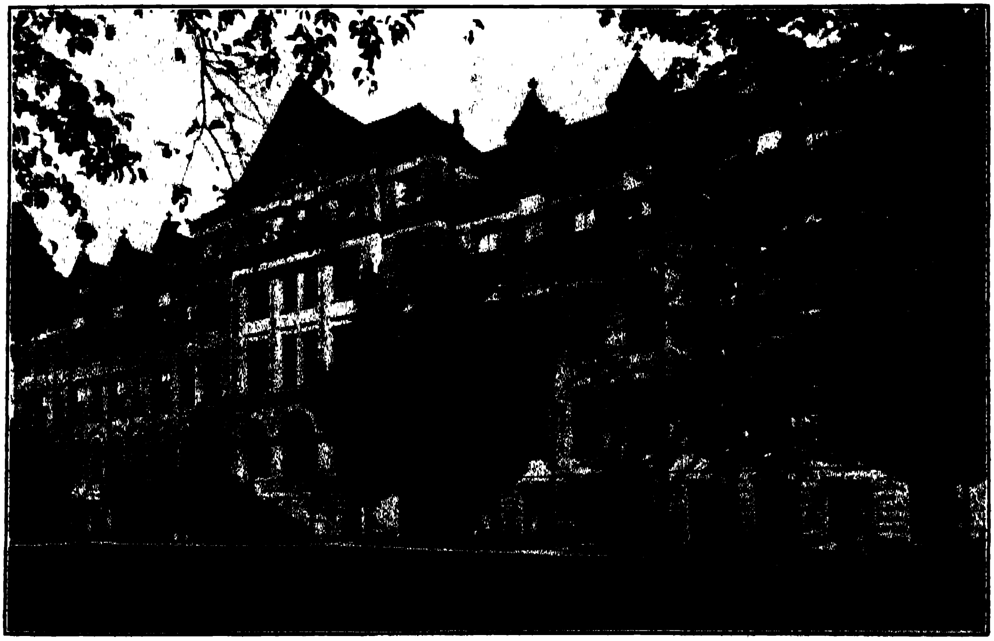
Five popular lectures, each of which is to deal with some phase of social, physical or biological science presented in a non-technical manner, will form the main portion of the part of the program for the public. These are to be presented on five successive nights at the municipal auditorium. In addition, an exhibit of scientific apparatus and methods is to be open to the public during the convention period.

The program will be found rich in the purely technical features which are still the main activities of the association. Besides the general sectional meetings which will take in all members under the group headings, twenty-six affiliated societies have announced their intention of meeting with the association. Also to be mentioned is the gathering of the Southern Society for Philosophy and Psychology which is meeting with the national group this year. There are many joint meetings and cross-section sessions on related and borderline subjects.

The varied program contains much material that will appeal to the non-specialist. A meeting has been arranged to commemorate Edison and his work. There are a number of symposia scheduled which are of more than ordinary interest. Professor Franz Boas, president of the association, leads a two-day



THE PHYSICS BUILDING



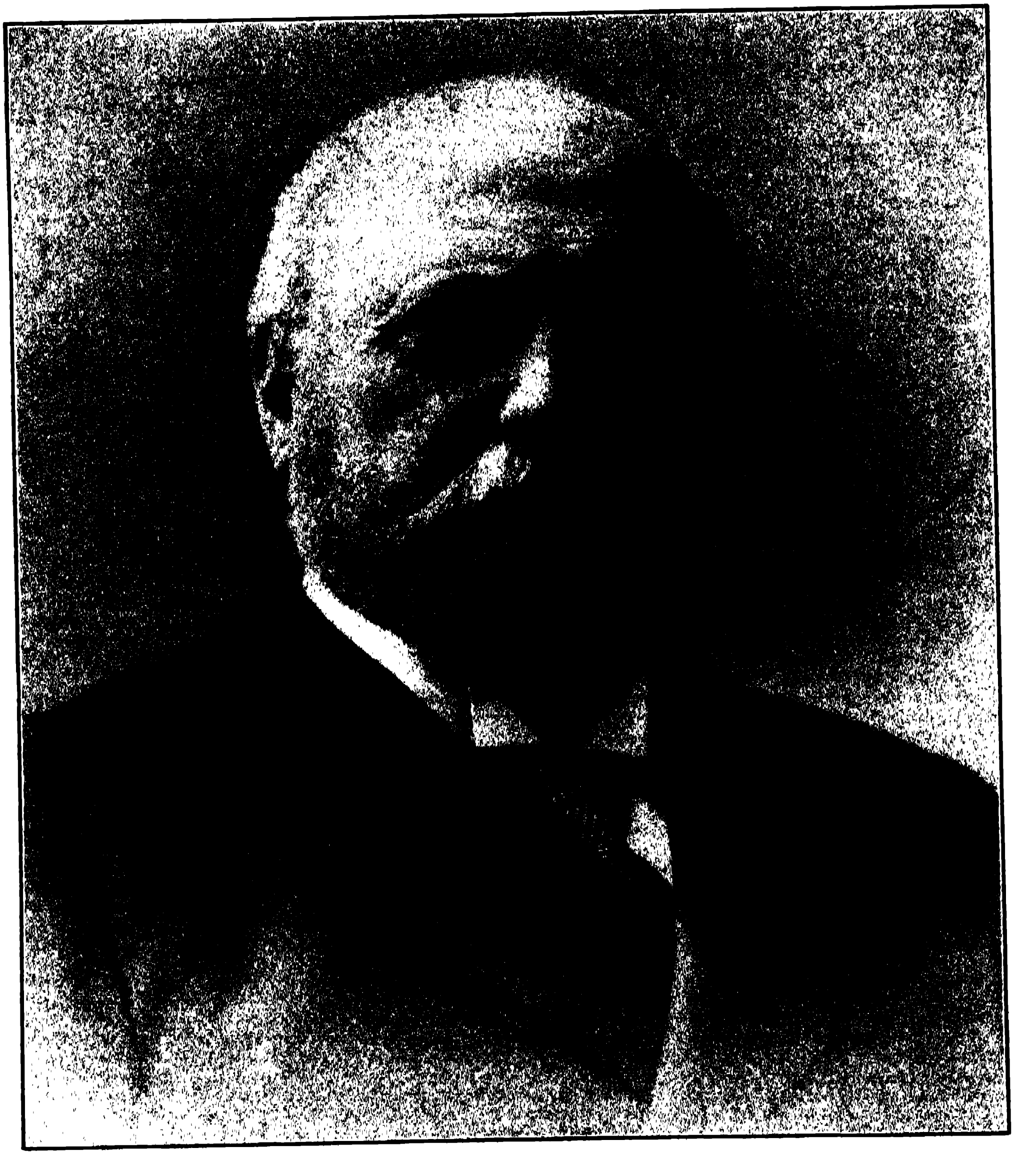
THE RICHARDSON MEMORIAL MEDICAL BUILDING

A TULANE UNIVERSITY CAMPUS SCENE

symposium on "Growth," and three sections of the association join in a discussion of "Social and Economic Institutions of the Mayas." Among the addresses will be the ninth annual Josiah Willard Gibbs lecture by Professor P. W. Bridgman, of Harvard University, on "Statistical Mechanics and the Second Law of Thermodynamics," and one by Professor S. J. Holmes, of the University of California, on "The Changing Biological Effects of Interracial Competition." Professor Richard P. Strong, of the Harvard Medical School, will give an address on some aspects of tropical medicine; Professor Irving Fisher, of Yale University, lectures on "First Principles of Booms and Depressions."

And so, between December 28 and January 2, the Crescent City, with its green golf courses in mid-winter and its interesting outdoor diversions, once more becomes the national focus of scientific interest, while the American Association for the Advancement of Science meets as the guest of Tulane University and the City of New Orleans.

J. H. H.



OTHNIEL CHARLES MARSH

THE CENTENARY OF OTHNIEL CHARLES MARSH

AT the recent meeting of the National Academy of Sciences, at Yale University, very proper recognition was made of the centenary of one of America's most famous men of science, Othniel Charles Marsh.

Marsh was born on October 29, 1831, at Lockport, New York. He was educated in the schools of Lockport and the Wilson Collegiate Institute, at Wilson, New York, in surroundings replete with minerals and fossils, which in turn gave the initial trend to his tastes and stimulated his lifelong passion for collecting everything that could possibly be of interest in nature and in art. Marsh's further training was at Phillips Academy, at Andover, where he prepared for Yale. Graduating from Yale College in 1860, he spent the next two years in graduate work at the Sheffield Scientific School, followed by three years of study abroad, at Berlin, Heidelberg and Breslau, where he came in contact with some of the master minds of scientific Europe. With this educational background, Marsh was ready to fill the first chair of paleontology ever established, which he did with eminence, from 1866 until his death in 1899. Marsh's work, however, was not professorial in the pedagogical sense; rather was he a collector and investigator whose researches had a far higher educational value—due to their world-wide appeal—than is often true of direct classroom instruction.

The material enumerated in Marsh's deed of gift, when on January first, 1898, he presented his collections to Yale University, included the following: vertebrate fossils, fossil footprints, invertebrate fossils, recent osteology, American archeology and ethnology and minerals, and shows the range of objects which his acquisitiveness prompted him to secure. Beside these there were fossil plants, and, in his residence, which together with its contents was later willed to Yale, there were paintings, and numerous examples of Japanese and other forms of art, as well as a rare collection of living orchids and the very extensive series of trees and shrubs which beautified his estate.

It was largely through Marsh's influence that his uncle, George Peabody, founded and endowed the Peabody Museum of Natural History at Yale, in 1866. One great aim of Marsh's career was the completion of the museum edifice, only the northern wing of which he lived to see, and which, at the time of his death, was so crowded with treasures that when, years afterward, they were moved into the present much larger building, the more than 600 vanloads of material completely filled it as well.

Marsh's principal interests lay in the three higher classes of vertebrates, as he published comparatively little on either fishes or amphibians, although his collections of these are rich, especially in the former group. Of reptiles, his chief concern lay with the dinosaurs, and it is a matter of profound regret that he never completed his study of the group, especially in its philosophical aspect for which his comprehensive knowledge so ably fitted him. His "*Dinosaurs of North America*" (1896) served to clarify greatly the existing knowledge of the anatomy, not only in part but in whole, of this diversified group. Marsh had planned no fewer than 27 monographs, but two of which he lived to complete. Of these the principal ones were to be on the Sauropoda, Stegosauria, Theropoda, Ornithopoda and Ceratopsia among the reptiles, as well as one on the fossil footprints and one on the toothed birds. Of the mammals he proposed to treat the Mesozoic mammals, Dinocerata, and Brontotheridae, as well as the evolution of the brain, and other subjects. Two quartos, the Ceratopsia and the Titanotheres (Brontotheridae), have been completed by his successors. In preparation for this stupendous work not only were the large collections made, both by his own means and through aid from government funds, but much in the way of preliminary description, illustrated by beautiful woodcuts which were later to form the text figures of the several volumes, was published in the *American Journal of Science.* There were also prepared a large number of lithographic plates in anticipation of future publication, and these are models of precision and execution. Marsh's aim in collecting was twofold, first to determine the geological horizon of each locality where a large series of vertebrate fossils was found, for he hoped to extend their utility as horizon markers, which had not, until that time at least, been recognized, and second, to secure from these localities large collections of the more important forms, sufficiently extensive to reveal, if possible, the life histories of each.

Even though the completion of the task he set for himself was beyond the powers of any one man and thus fell far short of attainment, nevertheless, what Marsh did accomplish and what will yet be learned from the unstudied part of his collections will add greatly to the sum of the world's scientific knowledge.

RICHARD S. LULL

THE SCIENTIFIC MONTHLY

FEBRUARY, 1932

AN ANT HILL

By Professor E. A. ANDREWS
THE JOHNS HOPKINS UNIVERSITY

IN the summertime everywhere about our dwellings little ants are busy digging into the earth to make their homes, and throwing up piles of earth as mere culm of no use to themselves or to others; but it is not such little ant hills that interest us now; rather the mounds found far from our habitation, ant hills of large dimensions, knee high or even waist high, whatever that changing yard stick may be.

NUMBERS, SIZE, DISTRIBUTION OF ANT HILLS

Of the many sorts of large durable hills built by ants, those of Europe are the best known, but here in the United States are many of equal importance, such as those of the ant *Formica exsectoides F.*, that so resemble the European *Formica exsecta.*

Formica exsectoides F. became famous from the researches of the Reverend H. McCook, who, in August, 1876, camped out in "The Ant City," near Hollidaysburg, Pennsylvania, where this ant, the local "pismire," had built up a settlement of some 1,700 hills. That this assemblage may well be called a city is evident from the facts that each hill harbors thousands of ants and the hills were not sparsely scattered, as with our rural dwellings, but found by McCook built many to the acre: thus he records 33 to one acre, 25 to another, an average of 20 to the acre near Hollidaysburg, while at the crossroads known as Warrior's Mark, the ant hills stood 55 on two acres and 74 on two acres and a half, yet the average was 30 to the acre; while a third populous region, Pine Hills, revealed thirty acres settled at the rate of some 59 to the acre.

These ant hills were of all sizes but some measured from 10 to 12 feet in circumference and from 2 to 3 feet in height; one was 12 feet across and 30 feet around; another 15 across and 37 around; the largest of all three feet and a half in height and 58 feet in circumference, and this stood upon the site of some former charcoal burner's hearth.

Nearly fifty years passed, and in 1924 this ant city near Hollidaysburg still continued, but greatly fallen from its former magnificence. Competition had become too keen; bipeds escaping from Altoona by the trolley that meets all the trains had set up their villas where the ants had shown the way; over some 20 acres but 50 occupied and 10 deserted ant hills remained to represent the 1,700 mounds in 1876. Still the station of the trolley there was labeled "Ant Hills"—and let us hope that term may remain after all the ant hills are crowded out by human occupation of that region.

This same ant builds its hills in Nova Scotia, Ontario, New England, New York, Carolina, Georgia, Wisconsin, Illinois; while in Maryland large settlements have been found in the mountains of the western counties and near the boundaries of the coastal and piedmont regions in Prince George's, Montgomery and Baltimore counties.

ANT HILLS IN MARYLAND

While one may come upon a single mound in some glade or abandoned field, more often where there is one there are several to be found scattered in constellations, with often a larger central mound and surrounding or nearby satellites that seem to have arisen from the process of colony formation or swarming resorted to by this ant in gradually extending its possession of a region.

Observations of mounds near Baltimore show that such an ant city is subject to waxing and waning, to extensions and retractions, of its boundaries, aside from direct interference from man, who, as a summer dweller in the woods, has no respect for the ant hills that preceded his bungalow.

Near Lutherville and Timonium, as far back as 1850, there were, according to the statement of Professor Philip Uhler, some very large mounds in a region of several hundred acres that had been deserted and unused for years after the exhaustion of old open diggings for bog-iron ore that left deep and lasting scars in the clay and gravel. With the growth of trees through fifty years the old mounds disappeared, all but mere circular ruins in the high timber, while many new mounds appeared in younger growths nearby. Thus, in 1905, 157 mounds formed a sort of town by themselves and 27 others an outlying village, inhabited by friendly ants that when carried from one settlement to the other acted and were received as if at home. These mounds were from 1 to 8 feet in diameter and from a third to two feet in height, but already some 67 were deserted mounds no longer inhabited. A second census taken in 1920 yielded 193 mounds, of which 10 or so were deserted. The greatest change, however, was in actual location of the mounds. The center of population had shifted. Many new mounds had arisen where there had been none and some of the old mounds had been deserted. At least 25 mounds remained active all the fifteen years. Mounds deserted in 1905 remained abandoned, and yet faint indications of them might still be traced in many cases. The village of 27 mounds grew in 15 years to contain 84 mounds.

Seeking reasons for the passing of mounds and the upspringing of others and the shifting of locations in certain parts of the settlement, we found that each mound may have its strongly marked individuality; a certain mound gained in fifteen years but two inches in height and only five in diameter, remaining of the same appearance, while another hill added to its two feet of height eight inches more, and to its diameter of five feet, three feet more. Six mounds showed an average increase of half a foot in height and two feet in diameter. The surface and color of mounds also was diverse but was evidently dependent upon the local soil and adjacent vegetation. But aside from such differences there were apparent reasons why whole series of mounds failed and others succeeded. Deserted mounds were often in shaded areas and successful mounds in sunny exposures. Mapping of mounds and trees in 1920—26 showed of 118 mounds 12 per cent. in the shade and 88 per cent. in the sunshine; in the shade 4 were occupied and 11 deserted; in the sun 94 were occupied and 9 deserted. Again, of the 67 mounds added to the settlement in 4 years, 18 per cent. were in the shade, and 80 per cent. in the sun; of these in the shade 3 only were occupied and 9 deserted; while of those in the sun 51 were occupied and 4 deserted. Sunshine and shadow are correlated with success and failure of these ant hills as useful habitations.

In these four years this portion of ant town had spread rapidly as western suburbs arising upon bare mine dump amidst sparse weeds and brambles, the vanguard of sapling black locust, oak and tulip that followed along after the mounds and seemed to threaten their continuance as they grew to be large trees.

In harmony with this we find such mounds in mining regions, mountain slopes, abandoned fields, glades and windfalls in the denser woods. On the one hand, too successful forestation and on the other field cultivation are inimical to the success of these builders of ant hills.

The basis for this dependence of the mound upon "place in the sun" will be better understood after we have considered the mound in connection with the two fundamental activities of ants feeding and breeding. Each mound is not a mere accidental accumulation of a ton or so of earth resulting from the mining operations of the ants, but it is a fabricated nest serving as the communal home into which the food is brought and in which all the young are produced and reared; it is the ants' home. Each mound is the property handed down from generation to generation in the family or social organization that inhabits it and is of kin to all the neighboring inhabitants of these communal houses.

Each hill is comparable to the nest of a hornet family and like that is roughly a conical structure gradually built up from small beginnings.

FORM OF THE ANT HILL

The ant hill seems to aspire to a cone as ideal, as fine sand dumped from a cart or the sands of an hour-glass, and all these cases are alike in that particles are arranged dependent upon gravity and friction, but in the ant hill each particle has been placed by the efforts of an individual ant working independently of its fellows so that the resultant shape depends primarily upon these innumerable dumpings centered about the ideal cone axis. (Fig. 1.)

While the eye may exaggerate the steepness of these little mountains, direct measurements as well as the tracings of photographs show that there is a great diversity in slope and form in different hills, depending evidently in part upon the materials used in different places and greatly influenced by vegetation. Few come to a conical point, all are rounded or flattened with various curves. Continuing the side slopes toward a theoretical apex we find the angles made there vary from 100 degrees to 150 degrees, the average of 20 mounds being 123 degrees as measured east-west and 128 degrees as measured north-south. Fifteen other mounds had the like averages of 116 and 119 degrees.

Though some mounds are quite symmetrical with equal radii, the majority exhibit more or less asymmetry in that the base is not circular and the faces east, west, north and south not all equal. Thus the above averages were due to some mounds having a longer south face which increased the angle at the apex. Frequently the north face is not only shorter but noticeably steeper and the apex of the mound is nearer to the north limit of the mound. Along with this the north face is often less well kept up and more neglected by the ants and more prone to be overgrown by mosses. Thus we have to some extent American representatives of the famous "compass mounds" of the Alps that enable mountaineers lost in the fog to recover their compass directions by observation of ant hills that plainly show differences between south and north.

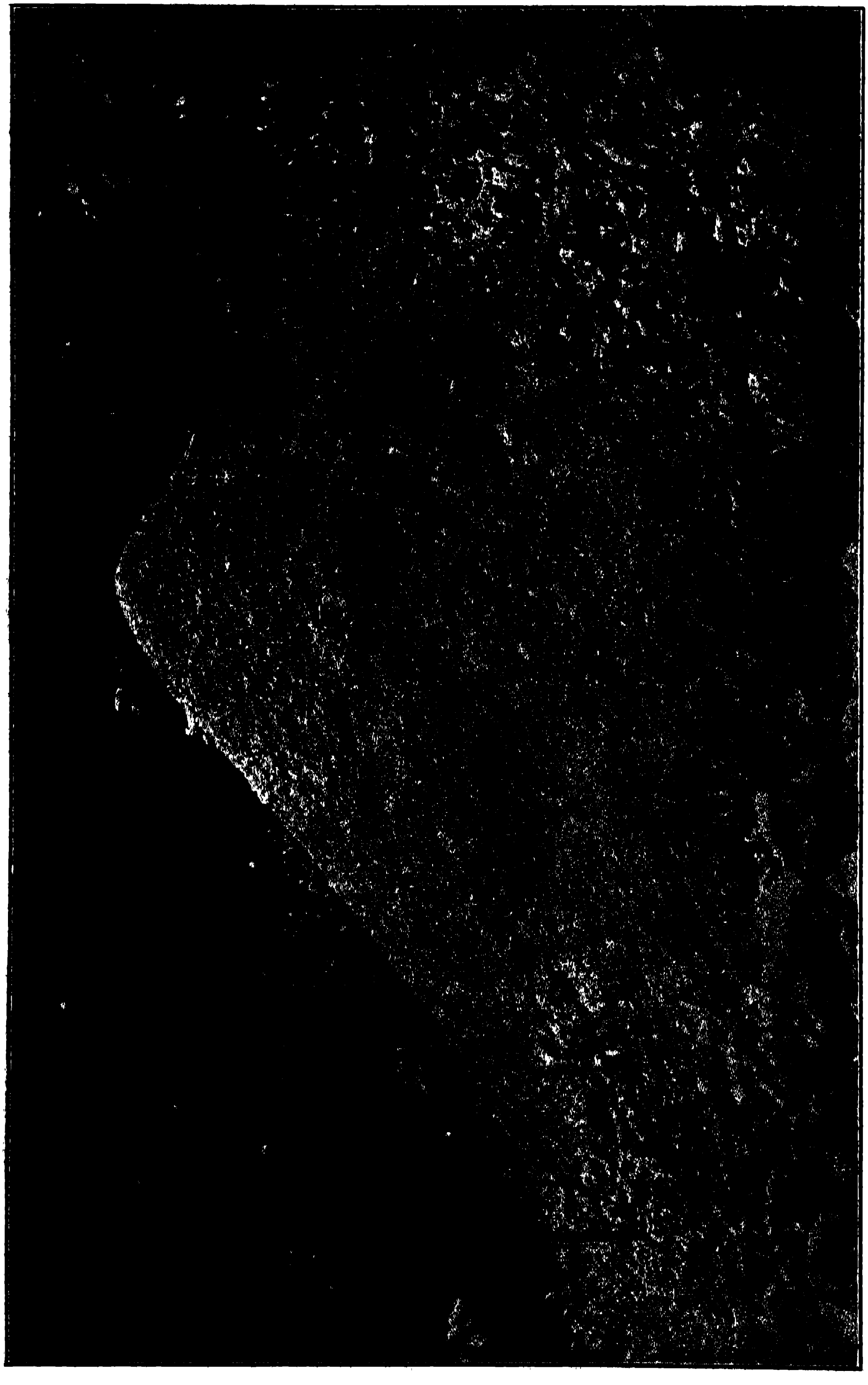


FIG. 1. ANT HILL

BUILT ON GROUND SLOPING TO N. W., HENCE THIS SIDE IS THE LONGER. FOOT RULE AT N. W. BASE SHOWS SIZE.

Some mounds show north slopes of 55 degrees to the horizon and some south slopes of only 19 degrees to the horizon here in Maryland. However, this extension of the cone in one direction is not always referable to compass or sunshine; sloping of the ground upon which the mound was built may bring about marked extension of the mound down hill. In this region of old mine excavations many ant hills arise upon their steep slopes and the ants ever persist in carrying up the particles of clay and gravel that tend to roll down hill with the wind-and-rain action and even with the kicking of the ants themselves. (Fig. 1.)

Despite this Sisyphus task the mound remains distorted down hill, and as in the accompanying photograph the long gentle slope may be northwest and not at all to the south, as it might be on the level where there is no special reason for the particles to roll more in one direction than in the other.

Architecture of the Ant Hill

The mound is not merely loose particles placed by the ant. The boy with stones to throw or the gent with a cane soon finds that the mound has an outer crust and a soft crushable interior structure. We may lift off the crust or roofing in small pieces part of an inch thick that crumble in our hands; earth mingled with more or less vegetable material, grass and leaf portions. The earth is sand or clay dependent upon the locality, and the vegetable matter, likewise grass and leaf portions, differs much in different regions. Pressure on the intact roof makes it yield and break in with from 2 to 25 pounds to the square inch, most often about 10 pounds. When there is much vegetable component in the adobe of the roof, penetration is easy, but on the other hand denudation is resisted and the steepest cones are built with utilization of pine needles as reinforcement. On the other hand, a rare mound may be found in which the stiff clay alone makes so firm a structure that a man may stand supported on the roof upon one foot. The roof is often strong enough to support a fox or owl that sits there to view the neighborhood, but the feet of deer crush through and leave breaks that the ants hasten to repair.

Observations in the field backed up with laboratory study of ants kept in confinement show that the strength of the roof is brought about by the rain that wets the dry materials placed here by the ants and draws them close together so that in drying they make a more homogeneous and coherent mass. The ants supply the raw materials and place them with reference to the ideal conical mound while the rain binds the loose building stones together and makes it a good roofing, but by no means an ideal one, as it is not rainproof and in long wet seasons the interior of the mound is muddy, indeed; so that one can sympathize with the native of Cecil County who marvelled that Providence had endowed the ant with such a fine house and yet with so poor a roof. However, we will see later that the roof is to be constantly reconstructed as the mound increases with the prosperity of the community, and a watertight roof might defeat this mode of enlargement. Thus the roof of the ant hill is made by bits of material wrested from the soil or picked up and merely laid in the right place, while the roof over the nest of a hornet is made of bits that are masticated and stuck together with secretions of the hornet.

With proper weather and warmth we see the ants running over the roof with such speed that the camera fails to show them. Up the mound a foot in three to five seconds; down the mound a foot in two to four seconds at 25° C. Those that run up soon deposit their burdens

FIG. 2. CLOSE-UP OF SMALL ANT HILL

SHOWING ROUGH COVERING OF STICKS AND STONES PLACED THERE BY ANTS. FOOT RULE RISING FROM NEAR BASE.

and run down again for more, carrying pellets of earth, bits of stone or sticks larger than themselves, or sometimes rare finds such as shells of small snails or the droppings of caterpillars or of mice. (Fig. 2.) Many of these objects are collected from afar. Colored sawdust was brought sixty feet back to the mound, other particles are ever collected from the base of the mound when they roll down, and the ants more than make good the loss from the mound as they clean the base down even below the natural level, removing the top soil till the coarse stones of the subsoil are revealed in a depression all about the mound base, forming a Brobdignagian pavement court at the front doors of the building, all the ants' entrances being small holes here and there about the base of the hill, leaving the apex and sides commonly with neither door nor window.

Every ant is provided with a pair of mandibles each a millimeter long with blunt cutting toothed edge .4 mm long on the far part of each. Bringing these together as ice tongs the ant seizes hold of objects most firmly. If possible this object is held up in the air in front of the animal and thus we see sticks ten times the length of an ant advanced wavering up the mound, and stones and pellets of earth larger than the ants bodily lifted and rushed forward up the slope. Bigger things are seized and dragged behind as the ant turns about and goes nimbly backward tugging stones that may weigh up to 170 mg, though the ant weighs but 10 mg; as if a man were to drag an automobile without wheels up a grade of thirty degrees!

Why, having got such a firm grip, the ant ever lets go of the burden is quite an unsolved problem; the ant may run in straight or sinuous path up the face of the mound even over the apex and round about or may stop at various places short of that and release the burden; sometimes the stone or pellet may be taken into some open door when there are such on the face of the mound. The load is dumped as if some wound-up internal mechanism were released after a time rather irrespective of the position upon the mound. Yet the sum total of all these dumpings makes the mound rise in conical form as if all the particles had been dropped as in an hour-glass from a central shute.

Moreover, there seems no collaboration amongst the ants. Each does as does another without any visible knowledge of what the other is doing, and never do two ants help move the same stone; if too utterly big for one to drag the stone is let lie, though it may be tested. The symmetry of the mound seems mirrored in each ant's mechanism, and if the symmetry is destroyed by local injury, by removal of large parts, even a half, the ants work the more upon that injured part till the wound is healed over. The apical region is the newer and softer part of the ant hill where loose objects have accumulated and have not as yet become stuck together. A penknife that stood up on the hardened lateral face sank an inch when stuck into the apical region.

Beneath the roof we find the internal structure of the ant home. The stick that penetrates the roof continues to penetrate with pressures of 30 to 50

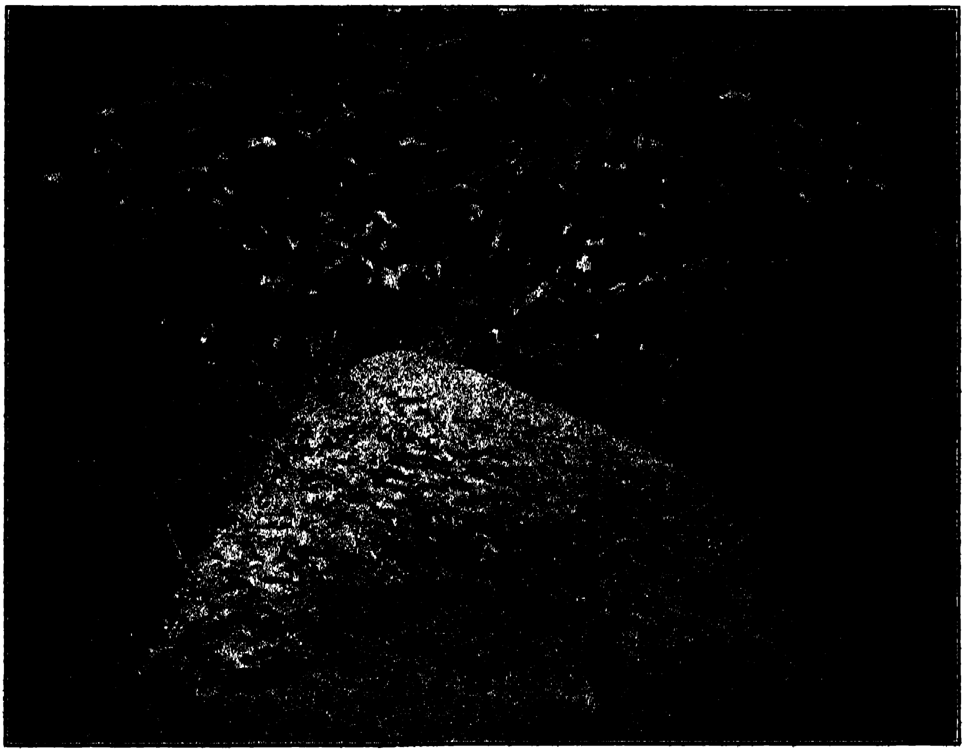


FIG. 3. ANT HILL CUT OPEN

SHOWING SPONGY INTERIOR IN THE SOUTH PART: THE NORTH FACE HAS THE STEEPER GRADE. GRASS GROWS ON THIS MOUND, BUT THE CATBRIAR IN THE BACKGROUND HAS BEEN KEPT OFF THE MOUND FOR YEARS BY THE NIBBLING OF THE ANTS.

pounds per square inch down a foot or more to the ground level or even deeper. In fact, the interior is not solid earth but a spongework whose walls collapse with pressure, and some of the bulk of the mound is mere air held in the internal passageways that constitute the real dwelling of the ant. Cutting into the mound the walls may crumble in sandy soil so that the structure is not easily understood, but in clay the walls stand firm and we comprehend that here is a continuous labyrinth in three dimensions occupying most of the space beneath the domed roof.

Some passageways seem rather horizontal and others approach the vertical, but here the ant has no such guide of structures at right angles all vertical and horizontal as the honey bee has in its hive. Many passageways run rather parallel to the sloping roof and others radial in the dome. Even in sandy soil we get the same idea of the structure of the labyrinth by allowing the mound to freeze in the winter and sawing into it; by infiltrating the sand with paraffine; by filling the passageways with plaster of paris and then washing away the earth between the passageways so that they now stand out as solid branching strands as shown in the illustrations; or by filling the passageways with paraffine, washing away the earth, replacing it with plaster and then baking out the paraffine to make a positive of the original mound. An ant coming home to its mound and entering at one of the many doors about the base finds itself confronted with a labyrinth with no exact horizontals, verticals, compass directions.

A horizontal view of a casting of some of these nearly horizontal passageways near the apex of the mound shows the irregular character of the branching of the former passageways here filled with plaster. The dark spaces are the regions from which was washed away the earth that once formed the solid buttresses that held the mound together. A vertical view of a like casting exhibits a tendency toward horizontal passageways and many diagonal, obliquely rising flights from story to story (the white areas are the sawed-off parts that continued the horizontal tunnels).

The earth buttresses here shown as dark spaces are all sizes and forms, but the tunnels or passageways are more uniform. Measurement shows them 4 to 20 mm in diameter and that the horizontal width is almost always greater than the height of each tunnel; the differences may be 2 to 3 mm, though often not so much, the norm of width approaching 9 mm and of height 6 mm. In such tunnels the ant has plenty of room, since with a length of 7 or 8 mm its antennae and its legs may spread apart about 7 mm and its height is but 4 mm; and the ant can crawl through a much narrower space when its legs are not so outspread.

Running at speed the ant very soon comes to a choice of ways, since the blocks or lengths from branching to branching are very short, scarce an inch, only 9 to 45 mm, with sometimes a norm of less than 25 mm. The solid earth not excavated by the ants is thus in buttress forms surrounded by streets, and in the denser labyrinth, where blocks are the shortest, to run all around a block the ant need go but four times 6 to 16 mm. that is, much less than 10 times the ant's own length. When the mound is abandoned and the roof no longer kept in repair these centers of blocks or buttresses remain as pillars of earth standing over the roofless mound.

The ant at each corner has a choice, as it were, of surface, elevated, or branching subways to advance in. The number of ways open to the ant at corners may be 3, 4, 5 or even 6. The streets or stairways do not diverge at equal angles; thus one corner presented

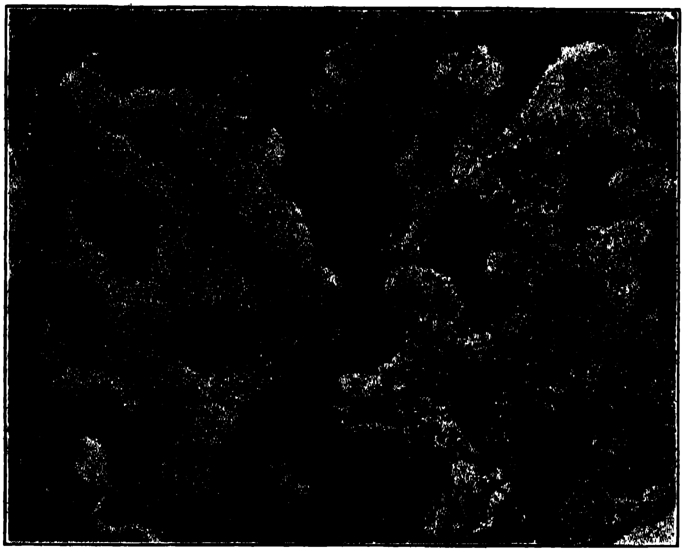


FIG. 4. TOP VIEW OF PORTION OF PLASTER CAST
OF INTERNAL STRUCTURE NEAR THE TOP OF A MOUND; SHOWING THE NETWORK OF PASSAGE-WAYS HERE FILLED WITH PLASTER OF PARIS; WHILE THE EARTHY PART OF THE NEST HAS BEEN WASHED AWAY, LEAVING THE DARK AREAS.

ways at angles of 11, 100, 130 degrees; another 95, 115, 155, another 50, 75, 120, 40, 72 degrees, all read clockwise. (Figs. 4, 5.) Compare all this with the most intricate of man's cities.

The parts of the mound most used by the ants and where most ants and young are to be found is far up above the basement entrances and must be reached by such unequally diverging and rising ways. Since the roof and upper levels seem to cut off all light the ants must find their way by mere chance, or else under guidance of other responses than those to light. It was Réaumur who saw that such labyrinths allow the ant to go up or down right or left or in any other way he may desire. But are there any signs along the way, and how do the ants read them in order to go to a region they prefer? These innumerable passageways show one limitation of the possible wanderings of the ants. Each has a definite floor. While ants can walk perfectly well upside down in these tunnels there is evidence that they habitually walk upon what is the bottom and not the ceiling, for each tunnel, except it be a rare vertical one, has the lower side plastered smooth with earth as if the feet of ants had trodden down the mud dropped in transporting the mined earth. The ceiling, on the other hand, is not smooth but rough with projecting bits of stone, etc., as if freshly dug out by the ants without any subsequent smoothing. Thus the ants seem to keep on the down side of all the streets they travel, rather than take the inverted elevated course.

During the summer this ant hill, with its roof and inside labyrinth that seems a maze that the ants must somehow learn to thread, serves as resting and breeding place and center of life of all the ants of one community. But as winter draws near more and more of the ants go down deeper into the earth by shafts they have dug leading rather straight downwards beneath the mound and diminishing in numbers with few side connections as depths increase from

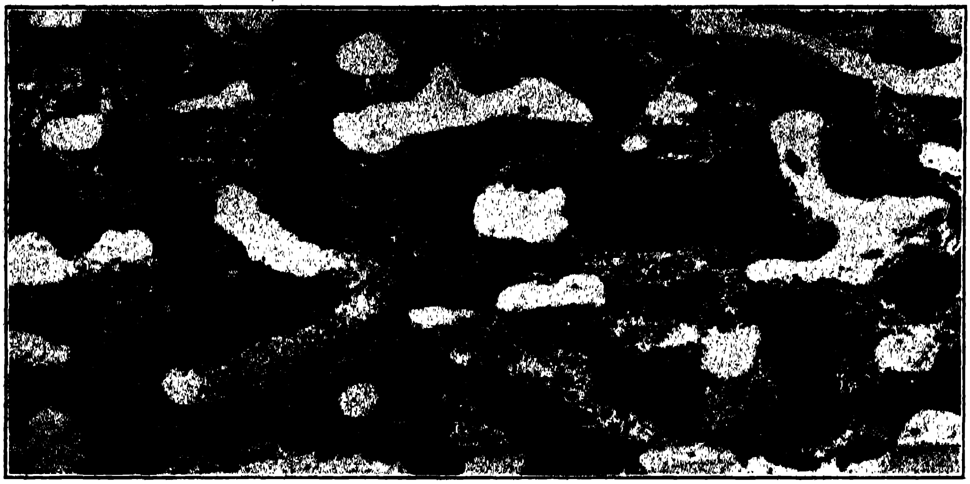


FIG. 5. PIECE OF PLASTER CAST

SHOWING SUCCESSIVE STORIES CONNECTED BY RISING WAYS ABOUT THE EARTHEN PILLARS, HERE SHOWN AS DARK, WHILE THE DEAD WHITE AREAS ARE THE SAWED-OFF CONTINUATIONS OF CASTS OF PASSAGEWAYS.

one to several feet. These tunnels in subsoil are lined with mud from the topsoil, and the linings may stand out clearly from differences in color, as in the burrows of earthworms, and these linings lead one to assume that these tunnels are frequently used, supposing that the lining is the result of accidental droppings trodden down by feet.

From the netted labyrinth down into these shafts all the ants finally descend and crowd together here and there in dense masses with compacted limbs. Here they rest during a third of the year in a torpid state, able to move their limbs and even to stagger about when exposed, but no longer capable of working.

As ants do not maintain a high temperature they soon are cooled below a working basis, and this dependence of activity upon temperature of the surroundings is most striking. It was found that some of these ants, kept for two hours at zero Centigrade, could at one degree not only move their legs but scrabble along weakly and walk very poorly at two degrees, could walk on the ceiling of a glass test tube at 2½ degrees, though slowly. Cooled down to 4 degrees below zero these ants remained inert but soon recovered when the temperature rose. In March or later or earlier, according to temperatures, the ants begin to come up from the depths and some emerge onto the outside of the mound.

There these ants begin the first work since last November, and it is the repair of the mound damaged by the winter or perhaps cracked from shrinkage. Later, food will be sought and later still breeding will begin. As far as known there is no storage of food down in the earth to carry the ants through the winter, but each ant may have stores within its own body; as all have shared with others during the summer, the ants may go into winter quarters with surplus and the entire community may pull through the long season of inactivity and little need of food. In this sense these ants "are a people not strong, yet they prepare their meat in the summer."

When a whole community was kept in

the laboratory it was found that after resting at low temperatures they could be aroused to work by connecting their dwelling jar by means of long glass pipes with other receptacles filled with earth, and then supplying dark heat to these pipes. The ants went to the warmer regions and basked in the heat, then dispersed and gradually came into the new region of earth to be excavated. Here they set to work as if to construct a mound. Moreover, for many days the ants that had been warmed went back and forth actually carrying sister ants from the cold jar through the long glass tunnel to the warmer abode. Let us then assume that it is the effect of temperature that is largely the cause of these annual treks from the mound to the subcellar and back again. The observations of Holmquist upon a closely similar sort of ant indicate that some individuals remaining in the upper levels respond sooner to the call to the surface and that these ants may induce other ants to go up.

It must be emphasized that in temperature responses, as in most other respects, each individual ant may differ much from other ants. If then temperature is a potent factor in getting the ants out of the labyrinth into the subcellar shafts and from these up into the labyrinth again (in the fall the subsoil is the warmer, in the spring the mound is the warmer) may it not be that temperature differences within the mound are important guides to the ant's finding its way? That such differences in warmth are to be found in different parts of the mound will be shown later.

Origin and Growth of an Ant Hill

The ant hill is a communal affair, and it is rare in this kind of ant that a new mound is started by just one ant; on the contrary a sort of swarming or colonizing process takes place, many ants starting a hegira to some new place. It may be that the entire community will then desert the old mound and thus it will stand deserted indefinitely and sink into decay. Thus when a mound and its inhabitants were taken many miles and transplanted into the woods of Johns Hopkins grounds the ants after some days of working on the old mound material all set off for a place they selected fifty feet away, on the edge of the wood in the sunshine, and there they built up a new mound with the new materials they found at hand. These ants carried with them their eggs and young and some of the quaint insects that have the habit of living only in ant mounds.

But the emigration may involve but a part of the whole community. For several days ants from a certain mound rather in the shade were studied as they ran forth forty feet to the north and established a new little mound in the open sunny place. Here again day by day old ants and young were bodily carried away from the old mound to the new (sometimes, to be sure, back again). Eventually the new colony cut loose from the parent community and has lived its own life for some years as a growing community, while the old parent community still continues in the same old place.

The architecture of a new ant hill starts with a very primitive expressing of ant activities, mere digging down into the earth, as common ants do. But several or many ants all dig at once, opening up several shafts near together. Biting their ways through the top soil and then the subsoil the ants bring out pellets of earth that are cast down near to the mouth of the shafts, accumulating as mere handfuls of roughly scattered earth pellets, rising up amidst the grass without order. The winter comes long before the mound is completed, but year by year the work is continued toward a perfected dome. The few inches of earth accumulated between the shafts tends to stop the mouths and must be ever removed by the ants till finally the mound is allowed to close over at the top and new openings are made near the base, since within the heaping mass side connections between the shafts were soon established allowing the ants to run from shaft to shaft and thus making a continuous network within the earth mass thrown up. Eventually the mass of earth thus mined and brought to the surface and heaped as a rude mound is supplemented by extensive collections of materials found ready on the surface of the earth and brought little by little by the ants to add to what they had mined. In all these efforts to build a home the weather is a most important factor; neither too hot and dry nor too wet and cold will serve the building ant well.

Observations of ants digging into clay in glass boxes and in glass tubes show that no progress can be made in dry clay nor in mud, while sand can be scratched away by the front legs, dog fashion. But when the clay is plastic the two jaws of the ant moving sidewise stick into it and are then brought together to wrest off a little bit as a man's hands shoved sidewise together might squeeze off clay. This requires great efforts on the part of the ant, painful to observe. Not only are the jaw muscles worked, but the whole head is twisted on the shoulders to worry off a bit of the tenacious clay, and the legs are braced so that no part of the ant seems at rest, giving a picture of a terrier biting at a root in its frenzied digging. Maybe twenty such minute bits, each 5 to 160 hundredths of a mm, are pulled loose and let fall, coming away with a noise that may be heard and imitated, and then rapid sweeping movements of the head and front feet shove the accumulated bits back beneath the worker who may gather them up in a pellet and carry this a short distance from the end of the drift to leave it there and to return to the work again and again. Meantime other ants may come near and pick up the pellets and carry them away farther, sometimes poking them into side cracks and vacant spaces, somewhat as honey-bees fill up crannies with propolis. Thus some are working as pick men and others as carriers, or cleaners up, and very slowly but perceptibly the tunnel advances into the resistant clay. An inch of clay in a tube was carried away and scattered along a foot distance. Ants worked the material by relay with each ant carrying the clay a short distance and so on till finally taken out to the surface.

The weather sets the rhythm the ants dance to; when it is too dry to mine the ants collect surface materials that may roll down the slopes as the heap assumes a mound-like form, but the ants carry this up again till the mound is strewn with crumbling dry particles. Then rain not only cements the roofing together but arouses the old primitive mining urge in the ants, who running over the roof enter here and there by minute openings that they soon enlarge and thus communicate with the ants within the labyrinth. Now each hole becomes a mine mouth, ants run in and out depositing pellets brought from within out on the surface so that soon the mound is pimpled over with little hillocks or steeper turrets, one about each shaft. With the drying sunshine the work slackens and the little chimneys are closed in at the top and by additions of pellets to the outside and the collecting of foreign material to add to the new roof the chimneys become little dimples and finally are lost in the gradual thickening of the whole mound surface. It seems that the materials that are thus rapidly brought out of the ant hill after a rain are mined out from

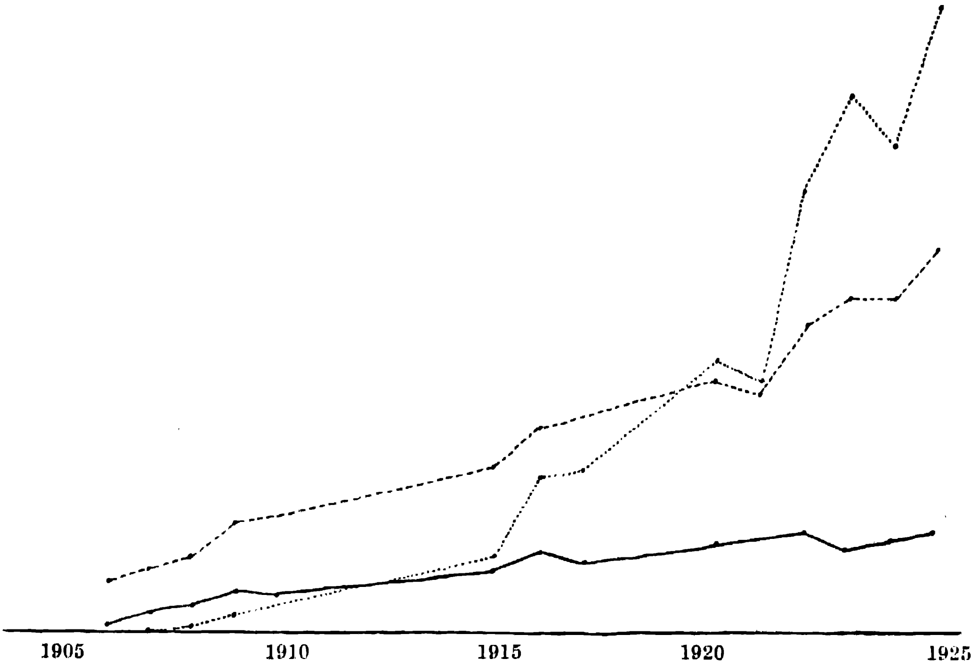


FIG. 6. CURVES TO SHOW GROWTH OF ONE ANT HILL FROM 1906–1924, INCLUSIVE.

THE LOWER CURVE SHOWS INCREASE IN HEIGHT UP TO TWENTY-SIX INCHES. THE BROKEN LINE SHOWS INCREASE IN DIAMETER UP TO 92 INCHES. THE DOTTED CURVE RISING HIGHEST REPRESENTS THE INCREASE IN CUBIC FEET UP TO 20 (MAGNIFIED BY FIVE AS COMPARED WITH THE OTHER TWO CURVES). ALL SHOW DEPARTURES FROM UNIFORM INCREMENT AND SOME SETBACKS.

the substances of the mound and, in part at least, from the substance of the old roof. Thus we get the picture of the mound advancing by waves of growth dependent upon the weather; long dry seasons making a thick roof from collections of surface materials and brief wet periods resulting in the tearing out of the old roof to make new attic labyrinths, the inside of the roof being put on the outside; it might be said that the roof is turned inside out without there being any laying bare of the inner life of the community.

By mining, collecting, remaking the roofs, the ants fabricate the mound and increase it year by year. An ant hill 3 inches high and 9 wide grew in a few months to be 5 high and 15 wide; the next year it was 6 high and 18 wide; the next year, 9 high and 26 wide: 6 years later 42 wide; and 12 years after that the mound was 88 inches wide with contents of some 30 cubic feet, as compared with 1/100 cubic feet, when first observed.

Curves representing this mound from 1906 to 1924, inclusive, show that growth was not uniform and might have setbacks in height and even in cubic contents, when the wear and tear of the elements was not entirely made good by the work of the ants (Fig. 6). Each ant hill, however, has its own individual vicissitudes and one may advance fast or slow and another fail.

FOOD BROUGHT TO THE ANT HILL

The ant hill may be large or small not only from age or youth but from the degree of success of the organization that owns it, and this in turn depends greatly upon food supplies. These ant hills flourish near small trees, not that the ant eats the leaves or the bark, but that they depend largely upon the juices of the trees as their daily bread. However, the juices of the trees are handed over to the ants by certain sucking insects, such as plant lice (aphids), tree-hoppers and scale-insects, which seem unable to utilize all the sugars they get from the sap of the trees and must needs cast off some of it, which, being sticky, is a nuisance if kept near and were best far removed.

Near every mound we expect to find such feeding trees, oaks, pines, black locusts or tulip-poplars from which processions of ants run back and forth, some ants coming to the tree from the nest and others returning from the tree to the nest, running rapidly in ill-defined paths in scattered open formation. Here again the effect of temperature is patent; though, if it be warm, the ants work all night the chill of evening slows their pace and they may run along at a slow rate of twenty seconds to cover one foot at 11 degrees while at 30 degrees they run it in only 4 seconds.

Coming then to the food tree up they go rapidly at the rate of a foot in 8 to 16 seconds at 25 degrees and helter-skelter down again even faster, a foot in 4 to 10 seconds, although they are loaded with clear liquid that makes their bodies swollen and translucent and adds to the weight they had going up actually about one third.

If you can follow these ants running in lines up the tree trunk you will find them spreading out along the branches and finally paying visits to the little suckers that produce the sweet liquid known as honey-dew. This is taken by the ants and eagerly drunk to fulness and ultimately carried to the home mound to be shared with young and old who lack, as more is taken than the individual needs and she then serves as a carrier for the community.

To seek out this honey-dew the ants may run a hundred feet over the earth and then up and out on the trees and yet find their way home with so many changes of direction. Though some ants run from source to source taking in many drops here and there others stand about for many minutes before they too return, but all ants near the source of food are most keen to pick a fight with any intruder and possibly this strong defense saves the mild producers of honey-dew from some attacks; if so the ants pay for their honey-dew by protecting the producers as well as acting the part of garbage man, who can salvage much good food from what is given him.

Getting the honey-dew is easy, since it is so freely offered upon mere suggestion that even clumsy man may induce its discharge by mere tickling, yet the running up and down the tree in the hot sun is hard work. At the bottoms of such trees we find holes that lead into the earth and descending ants entering in as if they might be going by tunnels back under ground to the ant hill. However, when we mark the ants we find that they come out again and either up the tree again or off over the surface of the earth. Examination proves these go-downs to be but small imitations of nests in which the ant does but rest a while and clean herself and sisters, and obtain the dampness and freedom from sunshine that home affords.

Important as is this honey-dew for the maintenance of the community it is by no means the sole food of this ant, and much meat food is brought back into the home, with some benefit to the forest, as often injurious insects are thus destroyed.

Nothing is so powerful as to quell the

fierce pugnacity that dominates the life of this ant. The wind, the rain-drops, all animal living things from cows to minute insects, if moving about, may be rushed at with open jaws ready for attack; strange chemicals, soft or sticky substances, a burning taper, plants growing upon the mound or near it, in fact, almost anything new and unusual may call forth this dominating pugnacity. Going about as with a chip on each of its six shoulders the ant attacks little insects single-handed, and only when they give very potent repellent juices does the ant retire to wipe its jaws; else the insect is killed and carried back to the mound, however far away. In killing, both ends of the ant come into play, the dull jaws seize and cut slowly, while the other end of the body ejects strong formic acid that may enter the wounds.

No insect is too large to attack, but with big prey several or many ants may take part. Each ant showed the same tactics, seizing, irrigating with acid and dragging away. When the prey was small the ant lifted it bodily and bore it forward high in the air, but if larger the one ant turned about and dragged the heavier prey as it ran backwards all the way to the home mound, which was somewhere behind the ant.

The great big insect seized by many ants is ultimately dragged home and into some entrance; but the way is long and beset with obstacles and much time is spent. To begin with, each ant pulls back from the prey wherever it has happened to seize it; the ants radiate out from the prey, sometimes the struggling mass advances in one direction, sometimes in another. The initial seizure and straining in all directions seems like the "stretching process" described by Major Hingston, who saw certain red tree-ants of India apparently killing their prey by stretching it in all directions; the prey being as upon a rack.

On this way home the prey may be worried and bitten till it comes in pieces, to be carried off separately. While juices are taken from the prey (which may be an earthworm yielding much nutrient fluid), as it is killed and dragged along, the carcass finally disappears within the darkness of the ant hill. What becomes of that food mass may be surmised from a study of mounds partly of glass within the laboratory; here such prey is let lie in some part of the labyrinth for many days, occasionally licked and apparently drained of its juices for the benefit of the community.

How so many ants, pulling each its own way, "having no guide, overseer or ruler," ever manage to bring home the large unwieldy cicada or earthworm is by no means easy to understand. At times we are tempted to give the chief credit to those stronger ants who are able to pull both the prey and such ants as may be riding upon it, or tending to drag it in some other directions. It may be that the real domination in this social organization is a sort of oligarchy of ants stronger in muscle and in inner urge to do as ants should do, while many weaker ants are subordinate, as exercising minor powers.

THE ANT HILL USED FOR BREEDING

The ant hill is more than a home for the ants in which to rest and feed and be protected. It is the nest in which the eggs are laid, the young reared, and the resting pupa in its spun cocoon cared for till the "callow," or weak, pale adult emerges to soon begin its duties for the commonwealth.

The emptied cocoons are tough little bags which the ants have no further use for and we find them carried out and cast loose upon the roof of the mound where they soon accumulate in numbers that cause comment and enable us to gain some idea as to the success of the colony that has thus brought as many new lives into it as there are emptied cocoons displayed. A very large ant hill having 212 cast-off garments to the square foot was estimated to have brought forth 13,144 new members of the family, enough to make good the losses from accidents and enemies of many kinds that tend to decimate the colony, though each ant may live several years, probably, if such fate does not overtake it.

All these new ants arose from eggs that were tended and cared for by the common working ants who feed the young as well as all the adults mutually; however, the eggs themselves were laid by a few specialists, the so-called queens, that have little part in the community save this all-important one of making the eggs for the workers to attend. While the workers have little part in egg production they have the needed powers to care for the eggs they did not produce. The queens may be few up to 33; one mound contained by actual count 8,228 workers and only 11 queens. As for the male ants they are found for but a short part of the season, and, however necessary for the continuance of the community, they perform nothing in the daily round of food getting and working at the ant hill.

The ant hill that serves for breeding year after year through some decades owes its continuance to very many factors, and the successful addition of young is not the least of these. Here again temperature underlies this activity. It is well known that ants in captivity do not breed unless the temperature is high enough and also the young grow but slowly or not at all if the warmth is not sufficient. As the ant seems to have little means of keeping its own body warm, in the cold, it can not furnish the needed warmth for the young but must trust to the finding of warm places and seasons, for breeding success. The mound furnishes just this needed heat for breeding, but the mound is only a transformer and conserver of heat, received from the sun, as appears from such curves as that shown by the results got by thrusting thermometers into all parts of an ant hill and reading them hour by hour through a September day and night. As the curves show, the air is warmed in the day and cooled in the night and this is true also of the earth. The ant hill also feels the diurnal pulse, but the sum of all the temperatures at apex and sides of the ant hill shown by the dotted zone (Fig. 7) is more uniform, not dropping off at night, as did the general soil outside the mound. In this case one aspect of the hill, the southwest face, is given a separate curve rising greatly in the day and falling low at night; this part acts as the furnace for the community, taking in much heat by day and losing much by night, but the whole mound tends to conserve some of the day's warmth and carry it over from daylight to daylight. Here again the weather determines the results. Long rain and cloudy weather makes not only a wet dwelling but a cold one, and work and reproduction are deferred or slowed up.

That the ant hill serves as incubator for the eggs and brooder for the young is connected with its architecture. Built of innumerable connecting rooms under a common roof that is greatly heated, more in one part than another, the walls heat the inner air and, as in the closed attic of a man's house, it is long before this heat is dissipated. Observing the ants in the open we find they collect their young and eggs in certain parts of the mound and according to both temperature and moisture conditions transport them hither and thither, generally through the internal labyrinth, but sometimes outside over the roof. In the laboratory also we see these ants carry their young from

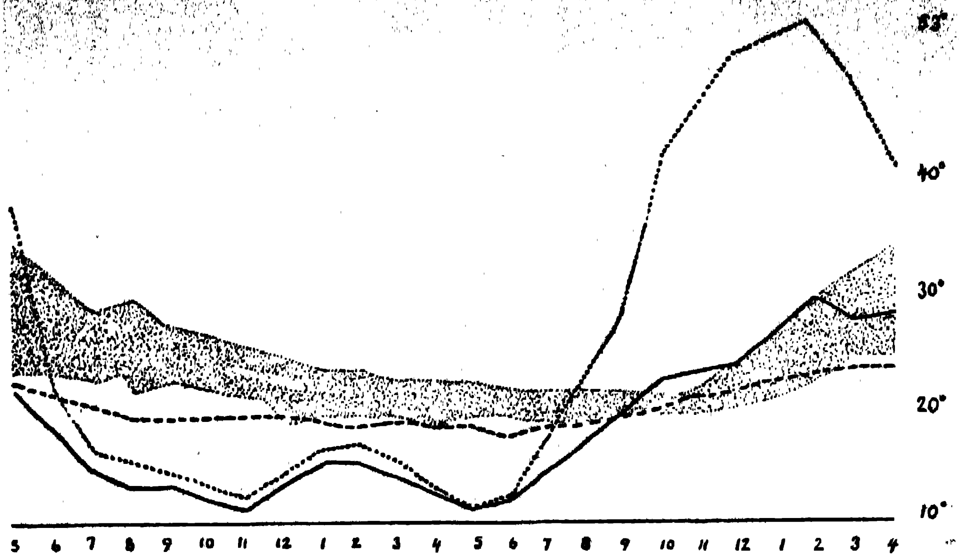


FIG. 7. TEMPERATURE CHANGES DURING TWENTY-FOUR HOURS IN SEPTEMBER.

THE DOTTED BAND INDICATES THE GENERAL INSIDE WARMTH OF AN ANT HILL VARYING FROM 20 TO 30 DEGREES BUT STAYING RATHER UNIFORM FROM 5 P. M. (ON THE LEFT OF THE DIAGRAM) TO 4 P. M. THE FOLLOWING DAY (ON THE RIGHT). THE BROKEN LINE REPRESENTING EARTH TEMPERATURES NEAR THE ANT HILL IS GENERALLY ON A LOWER LEVEL AND SHOWS THE EARTH NOT WARMED UP AS MUCH AS THE HILL. THE SOLID LINE CURVE FALLING LOW IN THE NIGHT TIME AND RISING TO A MAXIMUM ABOUT 2 P. M. SHOWS THE TEMPERATURES OF THE AIR. THE DOTTED LINE GIVES THE CHANGING WARMTH OF ONE PART OF THE HILL, THE S. W.; ALMOST AS COLD AS THE AIR IN THE NIGHT BUT RISING IN THE DAYTIME NEARLY TO 53 DEGREES, CENTIGRADE.

cooler to warmer areas, but there is a limit to the heat they select and they shun too warm a place as they cease also to work on the sunny exposures of the mound when the sunshine makes it too hot. The ant hill not being built at the equator of the world receives more heat on one face than on others and furnishes the choice of temperatures that the ants make use of. This heat may be held for some time after the sun is gone and so there is not as much interruption to breeding as would arise without this conservation, which depends upon the ant's engineering abilities.

That the heat rays and not the light of the sunshine serve the ant was shown by keeping an ant hill with its inhabitants in a dark room for more than a year. Here the ants proceeded to build, to mine, to collect stones and sticks, to get honey and meat food, to care for their young and to transport them, all with reference to greater areas of greater warmth produced by dark electric stoves. While this ant in nature lives in part in the darkness of the earth and in part in the sunshine of outdoors it can build, collect, find its way to and from the mound, feed and breed in the dark, under these laboratory conditions it had not before experienced.

Résumé

The ant hill is a ton or so of materials collected by the ants through many years of labor and put together to serve as the home for the group of thousands of ants that build it.

Each ant works individually without any apparent connection with other ants, having, apparently, in its own body the ideal of the ant hill that is to be and which once achieved must ever be repaired and maintained by its labor.

The hill that is built arises only under favorable conditions, and so many of these conditions are supplied by the sun that one may almost say that the ant and the sun have entered into partnership; the sun adding the capital in the form of heat and the ant supplying the plan and the executive ability for the enterprise.

The sun's contributions ebb and flow with the motions of the earth. In winter the business of the ant hill is at a standstill; the sun gives too little heat; the ants retire deep beneath the ant hill, where they rest in subcellars till in spring the sun again contributes to the hill such heat as will gradually draw the ants forth into activity.

Again every night insufficient warmth retards the work of the ant, though within the ant hill some of the warmth of the day is stored up and utilized by the ants. On the other hand, at midday there may be too much heat supplied by the sun and then the ants cease to work on the mound.

More indirectly the sun helps to shape the ant hill, for the clouds that the sun is responsible for modify the work of the ant and the rain that may fall upon the mound changes the character of the ant's work so that alternations of rain and dry are effective as alternations of day and night, winter and summer, in enabling the ant to cooperate with the sun towards the perfection of the ant hill.

No ant hills long continue except they have the optimum exposure to the sun; those in the shade are abandoned. Moreover, some ant hills show in their outward form the influence of the sun, being built by the ant more toward the sun than away from it.

In brief, the location of the ant's hill and its structure as well as the use it may be to the ants depends upon the warmth the sun furnishes.

The sun as well as the ant is responsible for these tiny mountains, these mere ant hills; and so much is the ant hill a product of temperature that we might fancy that sun-spots may leave some trace in these ant hills!

THE BROAD POINT OF VIEW IN PHYSICS

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WHEN Friedrich Nietzche some fifty years ago was proclaiming the new dogma of the superman, it is highly improbable that he had in mind the mathematical physicist. It is therefore a curious illustration of life's little ironies that at the end of the third decade of the twentieth century increasing popular interest should acclaim as the modern "Übermensch" the gentleman who can tell us what this universe is made of and how it really works, reciting the story in language so teeming with symbolism—with ψ's and ζ's and χ's—that to the humanist it must almost seem as if the ancient Greeks had come to life again to give heart to the classicists. It is not surprising that the modern versions of the "De Rerum Natura" should be so fascinating to the layman, yet there must also be a lurking bewilderment in the mind of the latter. Everything should be so clear, so manifest, and yet somehow even after reading Jeans and Eddington he finds it all rather elusive. Perhaps after all there is some excuse for pausing awhile and pondering over the old question—"What is physics?" It is a large question, and the answer to it will of course vary from age to age. But there are a few points of view which do not seem to suffer from over-emphasis. These we wish to examine here.

Definitions of physics have not been lacking. They run all the way from that of the late W. S. Franklin: "Physics is the science of the ways of taking hold of things and pushing them"—which must titillate the mental palate of the engineer, to that implied recently by Dr. Paul Heyl: "Physics is a state of mind," a definition to tickle the fancy of the philosopher. However, to define is ever difficult; perhaps one should be content to say that physics is the business of the physicist and then try to catch a glimpse of the latter at work. It is reported that when James Clerk Maxwell was a small boy he was fond of asking with reference to any new thing about the house: "What's the go o'that?" Nor was he content to be put off with a vague answer, but insisted on knowing the "particular go" of it. His later brilliant, though all too short, scientific career was a happy development of this childhood propensity. I think we may take this attitude as being significantly characteristic of the physicist—perhaps reaching its highest intensity in the mind of the physicist. What is his situation? He is confronted with a world of reproducible sense impressions of extreme variety. By a peculiar process of abstraction he separates certain portions of these from their surroundings for particularly detailed examination. He makes, for example, careful observations of motions of bodies and so develops the science of mechanics. He investigates what "meets the eye" and by a process which is still a mystery to many constructs the science of optics. And so the story goes. About all these things he weaves ingenious theories expressed in the symbolism of mathematics. And these very theories suggest new and more detailed phenomena for investigation. Thus the process of specialization has created that superb structure known as modern physics, so towering, so magnificent and yet unfortunately so little understood by those who gaze on it from the outside with so much admiration. There remains the task of gathering these specialized results into some kind of whole—the process of integration, never an easy matter. It involves taking a broad point of view, a very broad point of view, perhaps more often associated with philosophy than with science, but one nevertheless very necessary for the latter. There is a world which physics has constructed. We leave aside the question as to whether it is the real world, for the question of reality has curiously enough little interest for the physicist. What is this world, what is it like and what must we do to understand it?

The details of the world of physics are multifarious and not so easy to grasp as a whole. But there is one thing which is really far more important than knowledge of the details and which moreover we can accomplish: that is, an appreciation of the method by which this world is constructed. Now if one in search of information on this head were to enter a modern physical laboratory, he would undoubtedly see some rather queer things—whole structures of complicated glassware enclosing equally complicated and intricate metallic parts, switches and elaborate electrical circuits. The talk may be all of electrons and photons, but the operations boil down to opening and closing switches and in most cases watching the position of a spot of light as it moves along a scale. And the results of all the operations will be found ultimately to reside in a set of numbers representing coincidences between this spot of light (or something like it) and marks ruled on a scale. The words "pointer readings" have already been made so famous by Sir Arthur Eddington that it would seem almost needless to re-explain them here. Yet the significance of the fact behind them is so overwhelming that it will hardly suffer from over-emphasis. We get so used to talking in terms of concepts like mass, force, energy, pressure, to say nothing of electrons, protons and the like, that it is difficult for the outsider to realize that the numbers we attach to the marks representing these things are derived from nothing but such coincidences. To be sure the way from the pointer reading to the symbol may be long and thorny. After a hard day at the laboratory collecting his pointer readings the physicist used to go home and spend an equally busy evening making marks on many pieces of paper trying somehow to connect reasonably simple combinations of marks with his coincidences of the laboratory. We have employed the words "used to" advisedly, for alas, by the time the average modern experimentalist has finished a good day's work in his laboratory, he is so tired out that he is usually willing to leave the scribbling process to another individual who is paid to spend his days (and nights) juggling with symbols and piecing them with pointer readings. This is the race of theoretical physicists, now becoming perhaps more prominent than ever before in the history of science. All this is merely to emphasize that the job of constructing the physical world appears to call for two types of workers: (1) those who follow up hunches by collecting pointer readings with the greatest possible attention to the intricacies of experimental technique (now a branch of scientific activity in itself) and (2) those who follow much the same kind of hunches by chasing symbols around on a piece of paper, hoping to see ultimately the evolution of some simple connections with the pointer readings.

For we must clearly understand that the physical world is not merely a collection of coincidences, but an elaborate description in terms of a number of physical theories. Hence it is necessary to understand what a physical theory means. Perhaps the most striking thing about it is that it is expressed in terms of symbols. The world of physics is a symbolic world, a fact which can hardly be sufficiently emphasized. And it is undoubtedly this symbolic character of physics which gives the science much of its abstractness and so renders it difficult for many people to grasp. The extent of this abstractness is well illustrated in every field of physics and has always marked the power of its method. Even in what many would be tempted to call the simple and obvious case of the large scale motion of a material object, for example, the physicist has introduced the abstract concepts of velocity, acceleration, mass and force, etc., with appropriate symbols. Why should he do this? Is not the fall of a body a most simple sort of thing? Why should one try to make it more complicated? Why not leave it as it is—a simple interesting plain fact in the same category as that which children learn in their history books. The answer to these questions dates back to the time of Galileo, who sought to describe the motions of bodies so minutely that the assumption of a few simple relations should be competent to embrace all possible motions. These few relations are the principles of mechanics and if we tried to understand motion otherwise than in terms of them we should be forced to make a classified list of thousands, yes, even millions of individual motions each differing, in some slight respect perhaps, from the others. The question reduces after all pretty much to what we are willing to mean by understanding a thing. If we prefer to try to apprehend each separate motion as it presents itself to us in the simplest, crudest terms we know of, that is one thing. If on the other hand we prefer to put emphasis on a few things which appear to be characteristic of all motions so far observed and agree that every individual motion shall be understandable in terms of these few idealized relations and to the extent to which it manifests itself as a logical deduction of these relations, we are taking the attitude of the physicist, and indeed the scientist in general.

Without doubt the most amazing thing about physics is the fact that a careful description (involving abstract symbolism) of a very limited set of phenomena can suggest the assumption of a few simple relations among defined symbols from which by purely logical processes (*i.e.*, by the carrying out of operations well known to mathematicians) we can deduce the existence among these symbols of other relations which by an appropriate identification with operations performed in the laboratory can be shown to be confirmed experimentally. Herein we see indeed boiled down into small compass the method by which the physicist constructs the physical world. But such a highly concentrated statement contains elements elusive to a complete understanding and needs considerable amplification with commentary involving illustrations from actual physical theories. There are in particular several points deserving special emphasis. These will now be elaborated.

In the first place we should stress again the symbolic nature of the world of physics. It is difficult to overestimate the importance of a scheme whereby a mark on a piece of paper is made to represent a highly idealized concept which is put into correspondence with a certain group of laboratory operations of the type involving ultimately a set of pointer readings, through which numbers may be attached to the symbols. In this way we place at our disposal a set of quantities that can be handled in accordance with whatever mathematical rules we desire to follow. It must be clearly pointed out that more is involved than a mere shorthand rendition of a single laboratory operation. To illustrate, it is not merely as if, after going through a process involving the noting down of the difference in the levels of mercury in two tubes, the physicist decided to use the letter p to denote the result of every operation of this kind and attach numerical values accordingly. There is a deeper significance to the process, *viz.*, the strong feeling that p should represent something which is derivable from a combination of other symbols representing in turn more primitive concepts. The symbol moreover should not be tied to a single type of laboratory experiment but should have a meaning for and be assigned a value through a great many at first sight apparently quite different kinds of operations. In this way it takes on a larger meaning and the use of symbolism becomes an instrument of great power. Of course the freedom which the use of symbols confers in the manifold mathematical operations to which they may be subjected enormously widens the scope of theoretical physics. It is just as if our powers of description were correspondingly widened and deepened. Consider how barren the ordinary verbal description of the phenomena witnessed in a vacuum tube may be compared with the richness and fulness of the understanding of the same phenomena through the symbolic method. There is indeed economy in this procedure, as has been many times stressed, but it is the kind of economy that for given effort brings to us many times the return that would be possible by the use of words alone. And of course the whole procedure of the assignment of numbers to pointer readings would be very cumbersome without the symbolic method. Yet we must be careful to point out that the use of symbolism does not limit the physicist to any particular variety of mathematical process. We usually think of the analysis involving differentials and integrals when we think of theoretical physics and for good reason as we shall see later. But Faraday did not use this method in his study of the electromagnetic field, and as Maxwell insisted, Faraday's use of lines of force is as symbolic as the differential equations into which he translated Faraday's ideas. One of the great merits of symbolism is the infinite variety of form which it may assume. On the whole the physicist has been rather conservative, allowing the pure mathematician to run far ahead of him in the trial of new schemes. Recently, however, there have been signs of a new attitude, a willingness to introduce symbols obeying operations which while apparently bizarre are full of power. For example while in much of classical physics most of the symbols used are those to which numbers may be attached and which therefore obey the ordinary number postulates, there is now no hesitation in dealing with symbols representing definite physical concepts which do not satisfy these postulates, *i.e.*, for example, such that symbol A multiplied into symbol B is not equal to symbol B multiplied into symbol A. At first sight the introduction of such symbols seems needlessly to complicate matters and to scare away the uninitiate. But the only question involved is one of familiarity: the student need only recall that A and B may be "operators" which in general do not obey the commutative rule. To illustrate, if A represents the operation of multiplication by x while B represents that of differentiation with respect to x, then $A \cdot B \neq B \cdot A$ becomes perfectly understandable.

The fact that the world of physics is a symbolic one leads to another very important conclusion not clearly understood by the layman if we may base our judgment on semi-popular articles by scientists in various fields. The symbolic relations which constitute the fabric of theoretical physics are of course all implied in the initially chosen fundamental relations—the principles of physics—and the symbolic operations agreed upon for the construction of the theories. Hence it seems only right to admit that a physical theory is but a kind of description of the phenomenal world in terms of these initial relations. When a person asks us about a certain event he may say either: *Describe* to me exactly what you observed to take place, or, *explain* to me, if you can, exactly *why* that happened. Now both tasks are usually hard enough in everyday existence as well as in science, but I think most will admit that the second is much the more difficult of the two. It generally leaves us with a feeling of ultimate mystery to be resolved only by an appeal to some super-earthly power as a final "cause" for everything. The scientist and particularly the physicist may well be pardoned for viewing with suspicion the popular notion of explanation. His greatest successes have come through careful description in terms of a more or less abstract symbolism. This is after all the only "explanation" which he has to offer and it is certainly only fair to make this plain so that people who take science seriously may suffer no delusion as to its methods and accomplishments. The explanation of the physical universe consists in a description, the validity or desirability of which is to be judged by the success with which a large group of phenomena can be described in terms of a relatively small number of quite abstract concepts and relations symbolically expressed with the maximum economy in the use of symbols. To put it more crudely physics is interested in "how," not "why"—at least not in the sense in which children ask their flood of questions forever prefixed by that embarrassing adverb—hardly ever to be satisfied except by the last desperate reply, "Well, God made it so!" When the scientist discusses the "why" of things he really means in the last analysis the "how" and should leave the former to philosophers to handle if they wish. For science it is a superfluous word. To many scientists the above will probably appear to be a trivial discussion about verbiage, but a short conversation with the average layman will, it is believed, convince him that there is a real problem involved and to the confusion about it is undoubtedly due most of the average person's utter bewilderment about the nature of physical science or for that matter of science in general.

If we admit the essentially descriptive nature of physical theories the question arises: what is the test of the success of such a theory? This is a matter of great importance, but a somewhat difficult question to answer at all briefly. Obviously any phenomenon can be described in symbolic form if we are willing to use symbols enough and do not object to complication. It is no exaggeration to say also that the description is possible in a great variety of ways depending on the nature of the symbolic method chosen; some of these are seemingly more simple than others but all assume an air of familiarity after close study. Incidentally it seems that the view which regards the simplicity of a physical theory as largely a question of familiarity has hardly been sufficiently stressed. Why is it that we are so accustomed to say that a mechanical theory is simple, while a theory which discards mechanical concepts is "too complicated"? Is it not that our sense of familiarity with mechanical notions tends to give the mechanical theory an overwhelming advantage at the start? Recall how valiantly Lord Kelvin strove for the elastic solid theory of light against the electro-magnetic theory of Maxwell. He never could really "understand" the latter! The phraseology was outside the familiar mechanical mold.

The true test of the success of a physical theory is its ability to *predict*. Here is a matter that requires some elucidation. We have before us the task of describing or "explaining" in the physical sense some group of phenomena. As we have just pointed out, that is possible in a great many ways: we lay down some postulates and by mathematical deduction obtain a whole lot of relations which can be more or less readily identified with the known experimental results. We then say we have a theory, or, better, one theory. Our confidence in it is certainly materially strengthened if among the many derived relations there are some which correspond to physical facts as yet undiscovered, but which are later found to be as predicted. We may not care to go all the way with Dirac in his recent pronouncement that the "whole object of theoretical physics is to calculate results that can be compared with experiment," a point of view which deliberately enthrones prediction as the sole function of theoretical physics, and effectually ignores the rôle that a concise simple description of large groups of phenomena plays in its structure. Indeed it is possible to criticize Dirac's standpoint from the following consideration. Suppose someone propounds to me this problem: "I intend to put together certain pieces of apparatus in a certain way and go through certain quite definite operations. Now I wish you to tell me exactly what I shall observe." Let us imagine that you are a good guesser: you tell the gentleman what he will find. He then proceeds to find it. Does this make you a successful theoretical physicist? The illustration is extreme but it points out a difficulty nevertheless. The physicist will not soon get away from the notion that there is a physical world which it is his function to construct independently of his ability to answer certain questions about individual phenomena. However in all soberness it is safe to conclude that the one sure test of the ultimate validity of any physical theory is its ability to predict new physical experience. These two elements: shorthand description and accurate prediction should go hand in hand as the fundamental criteria for the judgment of the theories which express the structure of the physical world; but the more important is the latter.

We have mentioned the abstractness of physics in the sense of the—at first—unfamiliar concepts which the physicist uses. It is well to emphasize at the same time the importance of the notion of abstraction in the construction of the physical world. The significance of this idea can be appreciated from the following illustration. Suppose physicist A wants physicist B to make a study of, let us say, fluid motion. Does he thereupon invite physicist B to betake himself down to the bridge over the river and watch the flow of the water for a long time, making careful note of every phenomenon he witnesses? Much interesting information of a general nature might be secured in this way, but as a matter of fact, it is not a procedure which a physicist would be inclined to recommend. He has learned to recognize the extremely great difficulty of framing a precise description of any group of phenomena taken as a whole. It is indeed the kind of difficulty that most people learn to appreciate sooner or later even without the stimulus provided by formal education! No, if the physicist wishes to study the motion of fluids, he adopts a quite different procedure: he studies the behavior of a very small portion of fluid under highly idealized conditions over a very short period of time. That is to say, from the totality of phenomena connected with the motion of fluids he abstracts a certain limited section for special study. It is precisely in this way that he constructs differential equations to describe symbolically the phenomena under investigation. For it is just such equations which provide a symbolic description of experience on a small scale, *i.e.*, what is happening in a very small region of space over a very limited interval of time. The expression of the fundamental principles of physics in the form of differential laws is not accidental nor is it forced upon the physicist by any *a priori* necessity; it is merely an expression of his deliberate belief in the power of abstraction to lead to the most satisfactory structure for the physical world.

The implications of this method are too profound to receive anything like complete treatment in this place. Nevertheless there are a few points we must note. The method of abstraction leading to differential laws implies that the totality of any phenomenon has no effect on what happens at a particular place at a particular time, but that it is only events in the immediate vicinity which influence the event in question. In other words the "organism" point of view, so useful in studies of vital phenomena, is disregarded. Moreover, the use of differential equations leads to laws of physics which do not depend explicitly on particular places or particular times. This has been used by Maxwell as the criterion of causality in the physical world.[1]

It should also be noted that since the differential equations of physics are partial differential equations (*i.e.*, involve functions of several variables) they have a very agreeable wealth of solutions which need only the imposition of boundary conditions[2] to give them the precision which the physicist seeks in his final answer to any problem.

It will be remembered that the differential calculus was invented for the purpose of describing the physical world and on the whole we must admit that it has served its purpose very well. It is only in the quantum theory that difficulties appear in the process of abstraction and we meet with simple finite difference equations like the famous Bohr frequency condition $E_1 - E_2 = h\nu$ in place of differential equations. The law corresponding to such an equation has been called by Eddington "transcendental." Some have taken the view that since the realm of quantum theory deals with the atom, a discrete entity, we should no longer expect to be able to carry through our description in terms of differential laws—that there is no meaning to differentials when the symbol used is to be associated with something having a definite lower limit of magnitude. This standpoint has great plausibility but we must remember that it should not imply the impossibility of a description of atomic phenomena in terms of differential laws. It merely means that such a description may prove extremely complicated and may involve the introduction of new and unfamiliar concepts. If we turn back somewhat less than a century to the history of the endeavors to construct a picture for electromagnetic phenomena culminating in Maxwell's famous field equations (differential laws) we may perhaps gain a better perspective on our own modern problem and feel less sure of the ultimate overturn of the method of abstraction which has proved so powerful in the development of classical physics.[3]

A third important element in the construction of the physical world is the fact that the fundamental principles on which the structure is based are postulates, assumptions or hypotheses, in formal logical character very much like the postulates of mathematics. Since we often call them laws and indeed laws of nature, one may suspect that there is a wide-spread feeling that they express truths which the physicist arrives at directly by experiment: hence they are by nature inevitable. This view is erroneous, as a careful investigation of any physical law will show. Let us, for instance, consider for a moment the first law of motion, an important part of the foundations of mechanics. The usual statement is that every particle in the universe remains at rest or continues to move in a straight line with constant velocity except in so far as it is compelled by a force to change that state. It is very interesting to observe how this law is treated in many elementary physics texts. A rather common form of expression is that the law is rather difficult to prove experimentally, but one observes that a hockey puck will travel a great distance on smooth ice before coming to rest and the smoother the contact between ice and puck the farther will the latter go on being once set in motion: *i.e.*, if the contact could ever be made perfectly smooth, the puck would continue to travel forever. The only trouble with this argument comes in the kind of curve which the puck would follow; presumably it is unconsciously supposed to be a straight line. As a matter of fact if the ice were perfectly smooth, it would be a parabola, as is perfectly evident from the behavior of a ball when thrown into the air, where there is no "resisting" surface. When faced with this problem the reasoner may naturally reply: "But then you are neglecting the force which the earth exerts on the object. It is this force which draws the particle out of the straight line." It is a matter of some embarrassment to have to ask how one knows about this force and thus to extract the admission that our only precise knowledge of the force comes from the observed behavior of falling bodies. By that time we are, I take it, almost ready to accept Eddington's version of the first law: "Every particle remains at rest or moves with uniform velocity in a straight line except in so far as it doesn't." Does this mean that the first law is a meaningless absurdity or at best a tautology? Hardly that. It means that we must view the first law as a postulate expressing the assumption that when the acceleration of a particle is zero the influence of all the other particles of the universe on that particle vanishes. By the very nature of things this assumption can never be tested directly. It does not need to be. Its true significance lies in the fact that if we accept it as a basis for mechanics, we can build a structure closely approximating our actual experience of the motion of bodies. This is test enough for the physicist. It is not appropriate here to enter upon a lengthy discussion of the foundations of mechanics. We have merely wished to point out that the laws of motion are not experimental laws but postulates. How then does it stand with the other formulations of mechanics—Hamilton's principle, least action, etc.? The answer is precisely the same. Always at bottom we have to do with hypotheses whose justification comes from their simplicity of form, their ability to embrace descriptively large groups of phenomena, and their ability to predict previously undiscovered phenomena. It may be thought superfluous to be reiterating this view-point which is now so completely the stock in trade of every physicist. The reason why it is not superfluous is that there has always been a subtle psychological temptation to treat every successful hypothesis as an established law endowed with all the sanctity which the notions of inevitability and necessity are supposed to confer. The temptation is strong but dangerous. The physical hypothesis of one century may be quite incapable of subsuming the physical experience of the next as is well illustrated by the history of physics. Some one has said that the story of the development of physical thought is like a plain strewn with the bones of defunct physical theories many of which were based on hypotheses which seemed reasonable enough in their day. Think of the caloric theory of heat, the action-at-a-distance theories of electrodynamics, the elastic solid theory of light, all plausible but now fallen by the wayside. We must remember that from the logical point of view the hypotheses back of such theories are postulates of the same character as the seemingly most firmly established principles of physics like the conservation of energy and the second law of thermodynamics. The moral is plain: we must treat all such principles for what they are worth and no more and we must most particularly beware of philosophical arguments based on their supposed inevitability. A review of general scientific literature is sufficient to make clear that there is still some confusion over this matter. It is very possible, for example, that the tendency among some biologists to shun a physical basis for biology is founded on a misunderstanding of the most reasonable attitude toward physical laws.

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[1] We shall not attempt a discussion of causality, as such, in the present article. For its connection with the matter here considered reference may be made to: H. Poincaré, "Science and Hypothesis," Chap. IX; Clerk-Maxwell, "Matter and Motion," New York, 1920, p. 13; Moritz Schlick, *Die Naturwissenschaften*, 8, 461, 1920; 19, 145, 1931. See also H. Margenau, *The Monist*, January, 1931.

[2] See, for example, R. B. Lindsay, SCI. MONTHLY, 29, 465, 1929.

[3] Even in the case of statistical studies which deal with the behavior of large aggregates and which are becoming increasingly important in physics the differential method is still employed.

Passing now to our fourth point of emphasis, it is absolutely essential for the successful construction of the physical world that the fundamental concepts shall be precisely defined. In particular every definition must have a meaning in that it tells us how to carry out some definite operation or set of operations by which we can ultimately assign a number to a symbol. Judged by this standard, what shall we say, for example, of a definition of mass, one of the fundamental quantities of physical science, as the "amount of matter in a body"? This is still to be found in some elementary texts designed supposedly to provide the student with a thorough grounding in physics. It is pernicious, for it has no meaning unless "matter" has been previously defined and a precise group of operations connected with the word "amount." It is hard to imagine anything more calculated to confuse the thoughtful student than this mélange of words. Suppose one were to be presented with a lump of metal and asked to assign a numerical measure to its mass. Is there anything in the definition cited which would show how to do this? Now there is at least one very clear and precise method of defining mass in mechanics. To be sure it demands a bit of simple analysis with a few hypotheses and hence needs more words than the above pseudo-definition; but it is useful because it tells us something. We need not go into details at this place but may merely remark that what we have said about mass applies equally well to the important concepts of force, energy, entropy, etc., all too apt to be loosely used, particularly in philosophical discussions of physical problems.

It is perhaps a bit unfair toward the philosophers but a physicist can never recall without a chuckle what Maxwell wrote about Herbert Spencer's appearance before Section A of the British Association for the Advancement of Science at the memorable meeting in Belfast in 1874. There is a note of deep significance in the exquisite foolery which makes its quotation very appropriate even to-day:

> Mr. Spencer in the course of his remarks regretted that so many members of the Section were in the habit of employing the word Force in a sense too limited and definite to be of any use in a complete theory of evolution. He had himself always been careful to preserve that largeness of meaning which was too often lost sight of in elementary works. This was best done by using the word sometimes in one sense and sometimes in another and in this way he trusted that he had made the word occupy a sufficiently large field of thought. The operations of differentiation and integration which appeared, from the language of previous speak-

ers, to be already in some degree familiar to members of the Section, were, he observed, essential steps in the normal progress of evolution. It gave him great pleasure to learn that members of Section A were now turning their attention to these processes. . . .

Modern literature, scientific, philosophical, sociological and economic, hardly knows a more overworked word than "force." One rarely picks up a newspaper without seeing a reference to some kind of "force" doing something or other. There is nothing intrinsically objectionable about this; it is presumably a matter for literary experts to work on. Nevertheless from the standpoint of the physicist it is absolutely essential that the term force shall be precisely defined and once having been defined shall keep its definition throughout all physical discussions and, what is more important, in all philosophical discussions based on physical assumptions. Only in this way will the laity be saved from the utter confusion attending the talk about "cosmic" forces in the same breath as the force on an electron in a vacuum tube.

What has just been said about force might be said with almost equal justification about the term energy. The utility of this concept like that of force and mass is in direct proportion to the preciseness of the meaning attached to the symbol which is given its name. The student who in his first acquaintance with physics is led to think of energy in a vague wishy-washy way as something which can be "stored" in a tank and drawn off through a tap is bound to meet with great bewilderment in his later study, particularly in questions connected with the physics of atomic structure.

The attitude of the present article could be illustrated further, but probably the preceding considerations will suffice to bring out the significance of what has been called the broad point of view in physics. Much that has been said is by no means new to physicists but undoubtedly warrants greater emphasis than some of them care to concede to it. If it accomplishes nothing else it should certainly suggest to the reader the need for the never-ending scrutiny of the fundamental concepts employed in the construction of the physical world. That this is becoming more and more a problem of vital interest may be seen in the numerous recent discussions of causality and uncertainty particularly with reference to quantum mechanics. It would seem that some of this discussion is marked by a dogmatism and air of assurance that ill accords with the fundamental purpose of physics. However the limits of this article do not allow a complete consideration of this important question (see footnote 1).

In examining the foundations of physics the physicist is coming to grips with problems which are of constantly increasing importance for science as a whole, since the method of physics—the method of symbolism—seems to be our surest means for the description of all nature. If this statement is dubious and there are apparently some who think it is decidedly so, we may be sure of this much at least: the only way to settle the matter is to appeal to discussions of fundamental questions such as have just been suggested. Certainly physicists are only too glad to join with their colleagues in all fields of science and with the philosophers in further intensive search for the answer to that elusive problem of the ages: how do we know anything anyway?

PRELIMINARY EXPERIMENTS ON EXTREME VOLTAGE FOR THE BREAKDOWN OF THE ATOM

By Dr. A. GOETZ
CALIFORNIA INSTITUTE OF TECHNOLOGY

A NUMBER of most remarkable experiments to produce artificially the conditions of Rutherford's famous investigations concerning the breakdown of the atom by means of the α-rays of radium have been performed during the last few years in Germany by Drs. A. Brasch and F. Lange, of the University of Berlin.

If it would be possible to produce canal rays in sufficiently large electric fields, such as to come close to the energy of an α-particle emitted by radium, Rutherford's experiments could be repeated on a much larger scale. A simple calculation shows that canal rays of 1 milliamp intensity at sufficient voltage would produce the effect of several hundred pounds of radium. Several other advantages would arise besides the increased intensity of the effects: any such production of large fields should enable one to surpass the limited energies of the disintegrating radium atom, and furthermore the experiments would not necessarily be restricted to the use of helium, as is the case in the radioactive experiments.

The success of experiments of such kind is bound up in two conditions, the production of extremely high voltages and the construction of a discharge tube which withstands such potentials. For both problems the German scientists found a most ingenious solution.

The production of potentials of several million volts is well known to be exceedingly difficult and very costly, due to the fact that very soon the problem of satisfactory insulation of large, increased energies meets difficulties not yet surmounted. The losses in producing voltages of more than two million volts are almost prohibitive, and thus the task of producing 2 to 8 times larger potentials, necessary for the experiment in question, seems to be hopeless.

Here Drs. Brasch and Lange tried two new ways successfully. The first was to repeat the classical experiment of Benjamin Franklin, making use of the potential differences in the atmosphere during thunderstorms.

The region where thunderstorms are most frequent in Europe, situated in the Alpine region at the border between Switzerland and Italy, was selected. The Monte Generoso at the Lugano Lake was chosen for the experiments, since it is accessible and the configuration of its peak contracts the distances between equipotential planes of the atmosphere sufficiently to produce very large potential gradients. Here several different arrangements were tried of which the most successful one is sketched in Fig. 1.

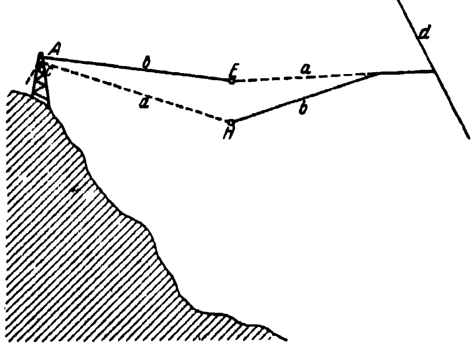

FIG. 1

At the upper end of a steep slope of the mountain the tower A was erected, which carried two connections with the cable d, the cable being suspended at two distant points not shown in the figure. The upper connection A–E–d consisted of the conducting part (b) and the non-conducting part (a), whereas for the lower part the insulating half (a) and the conducting one (b) were arranged in reverse order. The distance between A and the suspension point at d was between 500 and 600 feet. The altitude at which these were suspended was 4,500 feet above sea-level. Since A had the potential of the ground and d the potential of the atmosphere, the region between E and H worked like a spark gap of a condenser, and by varying the distance H–E (by lifting or lowering (a) by means of the pulley (c)) it was possible to measure the voltage which sparked across E–H. It was found that the arrangement worked not only by the immediate presence of a thunderstorm, but also due to induced charges by distant atmospheric disturbances. The distance of 54 feet was crossed easily by a discharge, which would represent a static potential of eight million volts. Considering, however, the short time over which a discharge lasted, the authors came to the conclusion that the potential must probably have amounted to between 14 and 16 million volts.

This proves that the atmosphere is able to produce potentials which are more than sufficient for the performance of the intended experiments as well as to prove that it is possible to collect these energies by rather simple methods, and many times less expensively than any artificial production by power plants.

The other problem—the construction of a discharge tube for such voltages—was solved in a similarly simple and unusual way. Here the principal idea is the following one: Experience in the construction of x-ray tubes for more than 300,000 volts has shown that the conduction of the charge at these voltages does not depend any more on the vacuum, but rather on the condition of the walls. Hence it is necessary to increase the size of such tubes to enormous dimensions, to create enough surface resistance so the tube may withstand such voltages. It goes without saying that the size of tubes for only several million volts would already be prohibitive. It was found, furthermore, that the gliding or conduction process along walls does not start immediately, especially if certain conditions are maintained. If it is therefore possible to have the potential act on the tube for a time so short that the wall charges are not yet set in motion a much smaller tube will work satisfactorily. Hence it is necessary to construct the wall of the tube in such a way as to make the motion of the charges very difficult. Such a construction was found by building a tube out of a large number of ring-shaped lamellae, as shown in Fig. 2.

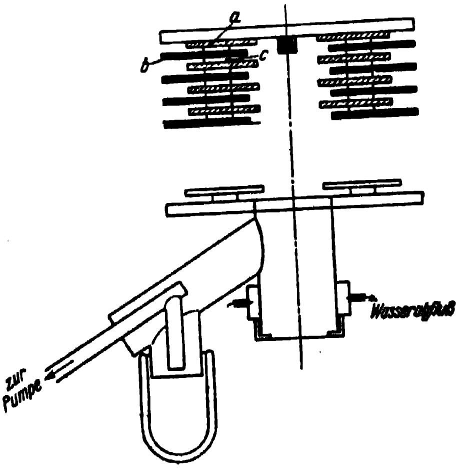

FIG. 2

Here the rings (a) consist of thin aluminum, (b) represent discs of a paper with very good insulating qualities, and

(c) are rubber gaskets. The whole structure was held together by pressure and formed a tube of less than three feet in length, of which the internal surface, however, had a length of 36 feet. The aluminum discs, producing an equal subdivision of the electric field, prevented the generation of fatal potential gradients along the walls. The tube was evacuated by a powerful mercury vapor pump and a liquid air trap shown schematically in Fig. 2.

By means of a surge-generator, which produced potentials up to 2.4 million volts lasting between one millionth to one ten-thousandth of a second, the authors were able to reproduce the conditions of atmospheric lightning on a small scale, fulfilling at the same time the condition under which such a discharge tube can work. The above tube was found to withstand two surges per second of 2.4 million volts and approximately 1,000 amperes, producing thus, in spite of the exceedingly short time of discharge, an x-ray intensity 10 to 100 times larger than the normal x-ray tubes running continuously at low potentials. The energy displayed in this tube during the time of discharge is many times larger than that of the total amount of radium which the earth contains, according to present estimates. The electrons necessary for the production of x-rays were introduced in the path of the discharge in a most ingenious way: Since the usual hot filament cathode could not be used on account of the presence of organic material, the gliding process of the charges along surfaces was utilized by introducing a sufficient amount of surface not subdivided, in the form of a bundle of porcelain capillaries. In a similar way, the ions for the production of canal rays were introduced into the tube by a stream of rarefied water vapor, which after having arrived at the anti-cathode was immediately condensed by liquid air.

The x-rays produced with the tube at potentials of 2.4 million volts proved to be equivalent to the α-rays of radium, penetrating lead 8 mm before losing half their intensity.

The canal rays of hydrogen produced at 900,000 volts penetrated aluminum to a depth of 8 microns.

After the success of this small tube, the construction of a generator producing 7 million volts and of a tube to use with it was started.

It seems thus that with these results experimental physics reaches a markedly new step in its development, since the work of Drs. Brasch and Lange shows that there are no longer any fundamental technical difficulties connected with the disintegration of atoms on a much larger scale than Rutherford worked in his pioneering experiments.

OUTSTANDING PROBLEMS OF THE OCEANOGRAPHY OF THE PACIFIC[1]

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INTRODUCTION

SINCE the physical and chemical properties of sea water and its circulation in the ocean basins determine the conditions of all the processes that take place in the sea, they are the features which demand first attention in considering the problems of the ocean. Therefore, this address will be devoted primarily to them.

Some elements in the marine environment are temperature and salinity of the water, the quantity of the gases and of the substances needed as plant food dissolved in the water, the relative alkalinity and acidity of the water (or OH^- and H^+ concentration), and the depth of penetration of light. Instability is characteristic of the ocean—there is movement apparently throughout the entire mass of the ocean water. The direction of the movement may be horizontal, upward, downward, or at any angle between the horizontal and vertical, including spirals. The maintenance of approximately uniform conditions within any oceanic realm is due not so much to the prevalence of a state of equilibrium as to continuous change, that is, the circulation of the water. Therefore, in evaluating the problems of oceanography, first rank must be accorded those that are concerned with oceanic circulation.

It is obvious that in a brief lecture, such as this one necessarily is, it is not possible to review the gradual development of such knowledge as we possess of oceanic circulation. Summaries of modern methods of hydrodynamical investigations of the sea have been recently published by V. W. Ekman, A. Defant, E. H. Smith and G. F. McEwen. During the past six or seven years there has been great stimulation of research on the problems of oceanic circulation. Much of the credit for this stimulation belongs to Alfred Merz, who contemplated an expedition to the Pacific and organized the *Meteor* expedition to the South Atlantic. Merz died in Rio Janeiro in August, 1925, but his plans for work have been carried out by the other members of the staff of the *Institut für Meereskunde* of the University of Berlin. Georg Wüst has published two longitudinal sections of the Atlantic Ocean and two for the Pacific, one for the Western and the other for the Central Pacific, and Lotte Möller has published sections of the Indian Ocean. Besides the compilations mentioned and the attempts of Wüst and Möller to interpret the results, there has been much other oceanographic activity, especially in the Pacific.

The work of the Japanese, the International Fisheries Commission in Alaskan waters and the Scripps Institution will be mentioned and later will be given its appropriate setting. Johannes Schmidt on the voyage of the *Dana* around the world has made important contributions. The greatest rôle during recent years in adding to knowledge of circulation in the Pacific was played by the *Carnegie*, which to the regret of all the world was destroyed in Apia Harbor in November, 1929, when its commanding officer, Captain J. P. Ault, lost his life. The results of other important expeditions are not yet available for use. They are those of the Russians in Okhotsk Sea and the northern part of the Sea of Japan, the Netherlands Expedition in the East Indies, and Sir Douglas Mawson's Expedition in the Antarctic Indian Ocean.

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[1] First paper in a symposium, "Major Problems of Modern Oceanographic Research," at the meeting of the American Association for the Advancement of Science, at Pasadena, California, June 17, 1931.

For this lecture an attempt has been made to utilize all recent publications, but necessarily they can not all be mentioned specifically.

OCEANIC CIRCULATION

It is desirable to begin this summary of oceanic circulation by noting a few principles that are generally known but need to be borne in mind during the following discussion.

The circulation of the waters in the oceans is due to causes which are fundamentally similar to those that produce circulation in the atmosphere. The main driving force is derived from energy radiated from the sun, but this energy does not impinge in equal amounts on equal areas over the surface of the earth. Because of difference in angles of incidence of the sun's rays, there is greater heating in the tropical and subtropical regions than there is in latitudes nearer the poles. Because of the inclination of the axis of the earth to the plane of the ecliptic, outside the tropics there is seasonal variation in the amount of heat received in each hemisphere, and, consequently, there is summer, when more heat is received, and winter, when less heat is received.

An important factor in directing the circulation of the waters of the ocean is the rotation of the earth on its axis. This, as is generally known, causes bodies set in motion to deviate to the right of the direction of motion in the northern hemisphere, and to the left of it in the southern hemisphere. Another factor that affects the movements of the waters in the ocean basins is that of the bounding continents and variation in relief of the ocean floor.

The movements of the atmosphere above the ocean surface exert important influences on the circulation of the waters of the ocean. Radiant solar energy and the deflecting effect of the rotation of the earth on its axis are largely the causes of atmospheric circulation, in a manner similar to their production of circulation in the waters in the ocean, but, since the density of air is much less than that of water, it is more mobile and, therefore, it may flow over the surface of the water and thus drag surface water along with it. The atmosphere also exerts two other important influences on water surfaces: one is because of evaporation; the other because of precipitation. If evaporation exceeds precipitation the salinity and, therefore, the density of the sea water is increased, but if precipitation exceeds evaporation the sea water is diluted and its density is decreased. Differences in salinity and temperature cause differences in the density of sea water. Unequal distribution of density causes unequal pressures and these produce movements of water masses.

Dynamical oceanographers have developed methods, which will not be summarized here, for computing the relative motions of water masses from their densities and the effect of the rotation of the earth on its axis.

Before beginning a survey of the circulation in the different ocean basins some features needed for understanding this circulation will be examined more closely.

EFFECT OF SOLAR RADIATION AND THE ROTATION OF THE EARTH ON THE CIRCULATION OF THE ATMOSPHERE AND THE SURFACE CIRCULATION OF THE OCEAN

If the earth were stationary and the sun revolved around it, there would be heating of the atmosphere and the waters of the ocean in tropical and subtropical regions and expansion of both air and water. Both air and water, where heated, would move upward and flow toward the poles, in the region of which both would be cooled, and there they would sink and return to the tropical and subtropical regions as lower cool currents. The scheme, however, is by no means so simple, for the earth rotates on its axis and this causes a deflection of the movements of both air and water in accordance with the principles which have already been stated.

The combined effects of the differences in the amounts of solar energy that impinge upon the surface of the earth, the rotation of the earth upon its axis and the existence of the continental areas are to produce in the atmosphere over the oceans five more or less permanent areas of high barometric pressure. Two of these are over the Atlantic Ocean and are respectively known as the North and South Atlantic "permanent highs." Two are over the Pacific Ocean, where they are known by names corresponding to those for similar areas over the Atlantic, and one is over the Indian Ocean. These highs are approximately in latitudes 30° to 35° on each side of the equator in the Atlantic and Pacific Oceans, and south of the equator in the Indian Ocean. Between the northern highs and the equatorial region in the Northern hemisphere we have the northeast trade-winds. Between the southern highs and the equatorial region in the Atlantic and Pacific Ocean we have the southeast trade-winds. The Indian Ocean differs from the Atlantic and the Pacific in that it is subject to monsoon winds which are partly controlled by the relative pressure in northern Asia. The monsoon winds, however, mostly affect the surface circulation in the Indian Ocean and appear to have relatively little influence on the deep-water circulation.

On the north side of the two high areas in the North Pacific and the North Atlantic and on the south side of the high areas in the South Pacific, South Atlantic and Indian Ocean are the regions of the west wind drifts. The west wind drifts of both the northern and southern hemispheres are marked on their polar sides by lines or areas known as the "polar fronts."

The surface oceanic circulation rather closely conforms to the general scheme of atmospheric circulation that has been outlined. We have in both the North Atlantic and the North Pacific in tropical regions a movement of the surface waters toward the western sides of the ocean basins. In the Atlantic the water moves along the eastern side of the islands off the North American continent and off the continent itself toward the northwest, north and northeast, and recurves in the region of the west wind drift across the Atlantic. On the eastern side of the Atlantic there is deflection toward the south and southeast, and ultimately a vortex is completed, within which is the Sargasso Sea. There is a similar vortex in the South Atlantic. In the North Pacific we have the Japan current which, as is generally known, flows northward and northeastward off the east Asiatic coast, eastward across the Pacific south of the Aleutian Islands, and then is deflected toward the south and southwest.

Westward flowing equatorial currents are well developed in the Atlantic Ocean, where they lie mostly north of but near the equator. There is no strongly developed equatorial counter current in the Atlantic. However, the Guinea stream, which is very near the equator, flows from west to east. In the Pacific the equatorial currents are strongly developed and there is a pronounced equatorial counter current which lies slightly to the north of the equator.

As a result of the direction of the winds, which act upon the circulation of the waters, we have on the west sides of continents, along a more or less meridional line, upwelling of cold waters. Before this lecture is finished it will be shown that the scheme of oceanic circulation which has been outlined is of fundamental importance in controlling the distribution of marine organisms.

The Indian Ocean will, as regards the surface circulation, be treated only casually. As has already been stated the surface circulation is influenced by the monsoon winds. The equatorial counter current during the period of the northeast monsoons lies between latitude 10° south and the equator. During the southwest monsoons it is obscured. The south equatorial stream in the Indian Ocean is distinct throughout the year, but it is more pronounced during the period of the southwest monsoons. There is a north equatorial stream, really a westward monsoon drift, during the northeast monsoon (northern winter and southern summer); but during the southwest monsoon the direction of the surface drift is reversed and there is no north equatorial stream.

CONFIGURATION OF THE OCEAN BASINS

Although no attempt will be made to describe the different ocean basins in detail, a few of their more salient features need to be mentioned.

The Atlantic Basin. The S-shaped Middle Atlantic Rise extends almost the entire length of the Atlantic Ocean and divides it into two troughs. That part of the ridge north of the equator is known as the North Atlantic Rise, and that south of the equator is known as the South Atlantic Rise. Free communication between the northern end of the Atlantic Ocean and the Arctic Ocean is obstructed by the Iceland Swell, which extends from the northern end of Scotland to Iceland and is continuous to Greenland, and by the relatively shallow water on the west side of Greenland. Conditions on the two sides of the Iceland Swell are very different as the section across the part of it between the Shetland and Faroe Islands, known as the Wyville Thompson Ridge, as given by Murray and Hjort, plainly shows. On the north side of the ridge the bottom water, at a depth of about 800 meters, has a temperature of 0° C., whereas on the south side the water at a depth of 1,600 meters has a temperature of 4° C. Shallow bottom holds back from the North Atlantic the cold water of the Arctic Ocean. Two important submarine ridges that affect the circulation in the southern part of the East Atlantic are Walfish Ridge, which extends from the west coast of Africa in latitude 20° S. southwestward to join the South Atlantic Rise in latitude about 35° S., and the Atlantic-Indian Transverse Rise, which is an abruptly bent eastward continuation of the southern end of the South Atlantic Rise. In the southern part of the West Atlantic trough there are two submarine elevations of significance as regards the movement of the ocean waters. One of these is the Rio Grande Swell, which extends from the east coast of South America, latitude about 30° S., to join the South Atlantic Rise. The other is the Antarctic Archipelago, an arcuate series of ridges which extends from the southern end of South America towards the east and then bends westward to join Antarctica on the west side of Weddell Sea. Between Walfish Ridge and the Atlantic-Indian Transverse Rise there is the Cape Basin, which connects with the Indian Ocean. Between the Rio Grande Swell and the South Shetland Islands is the Argentine Basin which connects with the South Polar Basin, which in its turn lies south of the Atlantic-Indian Transverse Rise and communicates with the Indian Ocean. From what has been said it will be obvious that the Atlantic Ocean at its south end has two deep water communications with the Indian Ocean.

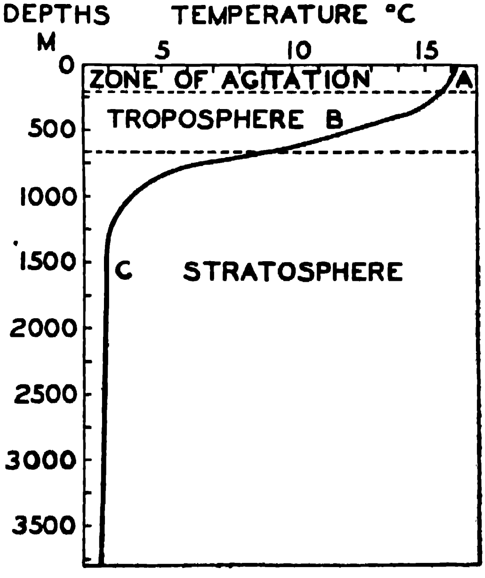
The Pacific Basin. The configuration

of the floor of the Pacific Basin differs in several important respects from that of all the other ocean basins. There are in it no continuous, more or less meridional, elevations such as the Middle Atlantic Rise, and there are no great transverse ridges such as Walfish Ridge and the Rio Grande Swell. At its northern end the Pacific is more or less cut off from the Arctic Ocean by the shallow water in Bering Strait and the Aleutian Islands, but some water appears to enter the North Pacific from the southwest section of Bering Sea. On the west side of the Pacific there is a succession of island arcs behind which are partially enclosed seas. One of these seas, the Okhotsk Sea, appears to be a source whence a part of the cold water in the North Pacific is derived. The southern end of the Pacific is widely flaring and is in communication with the waters on the north side of Antarctica and with the waters of the Indian Ocean south of New Zealand and Australia. On the east side of its southern end communication with the South Atlantic is obstructed by the island arc of the Antarctic Archipelago, which has already been mentioned. Although there are within the Pacific Basin numerous ridges, such as the Hawaiian Ridge, there are none that extend entirely across the ocean basin and divide it into north and south sections, such as is the case in the Atlantic basin. The bottom conformation of the Pacific is such as to allow a more extensive meridional movement of bottom waters and also a more unobstructed movement between East and West than in the Atlantic.

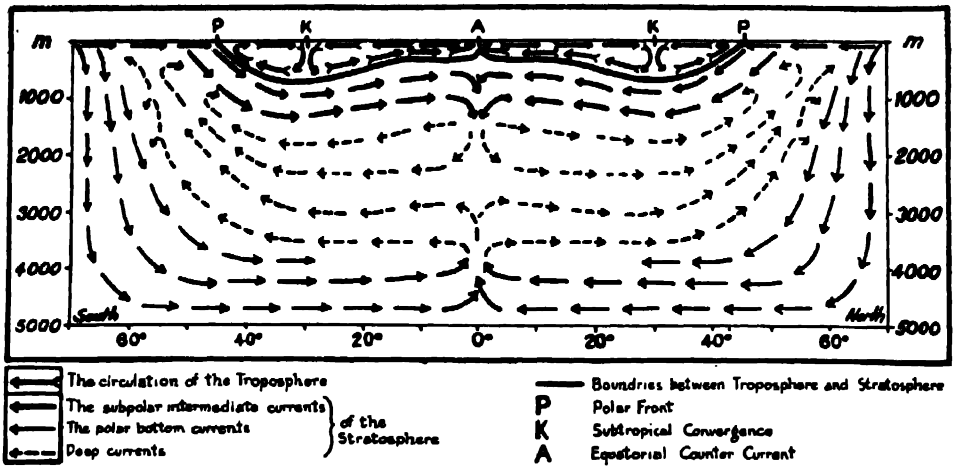
The Indian Ocean Basin. The Indian Ocean differs from both the Atlantic and Pacific Oceans in that its northern margin extends a relatively short distance north of the equator, and in that it is entirely cut off from any immediate source of water from the Arctic region. On the south the Indian Ocean is in fairly open communication with Antarctic waters, except that there is a rather large area of less than 2,000 fathoms deep above which rise Kerguelen, Prince Edward and other islands. Toward the East the Indian Ocean is in free communication with the southwest corner of the Pacific, and toward the West it is in free communication with the Southeast Atlantic, by means of the Cape Basin and the South Polar Basin.

The Deep Sea Circulation

A schematic section of conditions in the ocean within the tropical, subtropical and temperate regions will first be presented. According to A. Defant, the waters of the ocean in those regions may be divided into a troposphere and a stratosphere. The troposphere includes a surface zone of agitation of somewhat less than 100 meters in thickness, in which there is only slight reduction in temperature from the surface downward. Between the bottom of this layer and a depth of about 1,300 meters there is rapid decrease in temperature (the "Sprungschicht" of the Germans and



Vertical section of ocean water for tropical and subtropical latitudes. After Defant.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m
1000
2000
3000
4000
5000
South
North
60°
40°
20°
0°
20°
40°
60°
The circulation of the Troposphere
The subpolar intermediate currents
The polar bottom currents
Deep currents
of the Stratosphere
Boundries between Troposphere and Stratosphere
P Polar Front
K Subtropical Convergence
A Equatorial Counter Current

DIAGRAMMATIC SCHEME OF CIRCULATION IN A SYMMETRICALLY CONSTITUTED OCEAN. AFTER WÜST.

the "Thermocline" of writers in English) until the temperature ranges from 2° to 4°. Below the Troposphere is the stratosphere in which the temperature decreases very gradually and shows relatively little variation. In both high and low latitudes stratospheric water comes to the surface.

Wüst has suggested the following general scheme of circulation in an entirely symmetrical ocean: In the region of the equatorial counter current there is upwelling, and warm water moves on the surface away from the equator toward the north and south. In latitudes about 30° north and south there is sinking. On each side of each area of sinking there is a circulatory system, in one of which the water moves southward or northward, as the case may be, toward the equator, and in the other the water moves northward or southward, as the case may be, toward the polar front. Corresponding to the two polar fronts there is sinking of colder water of lower salinity which then moves from both the north and the south toward the equator as an intermediate current. In the region of the poles, polar water, because of its lower temperature and somewhat higher salinity, sinks and moves as bottom water from the poles toward the equator. According to Wüst, in order that the circulation may be compensated, there must be above the bottom water and below the intermediate current, a deep current that moves from the equator toward the poles.

This general scheme of circulation proposed by Wüst has been attacked by Castens. The criticism of Castens may be well founded, but nevertheless Wüst offers a working hypothesis which can be tested by the application of the dynamical methods developed by Bjerknes and other investigators of the fundamental principles of dynamical oceanography. Using Wüst's scheme of oceanic circulation a brief comparison may now be made between the circulations in the different ocean basins.

The Atlantic Basin. It has already been stated that the Iceland Swell and the shallow bottom west of Greenland almost completely isolate the main body of the Atlantic water from Arctic water on the north. There is no such obstruction between the South Atlantic water and the Antarctic region. Therefore, there is a sinking of surface water from the Antarctic in the region of about 50° south latitude. This water pushes itself northward as a current of intermediate depth and relatively low salinity, 34.00°/oo to 34.70°/oo, nearly as far as 20° north latitude. Near the Antarctic Continent cold bottom water of a salinity between 34.65°/oo and 34.70°/oo sinks in the west basin and pushes itself northward in the West Atlantic Trough nearly to the equator, but in the East Atlantic Trough the northward extent of this water is cut off by Walfish Ridge.

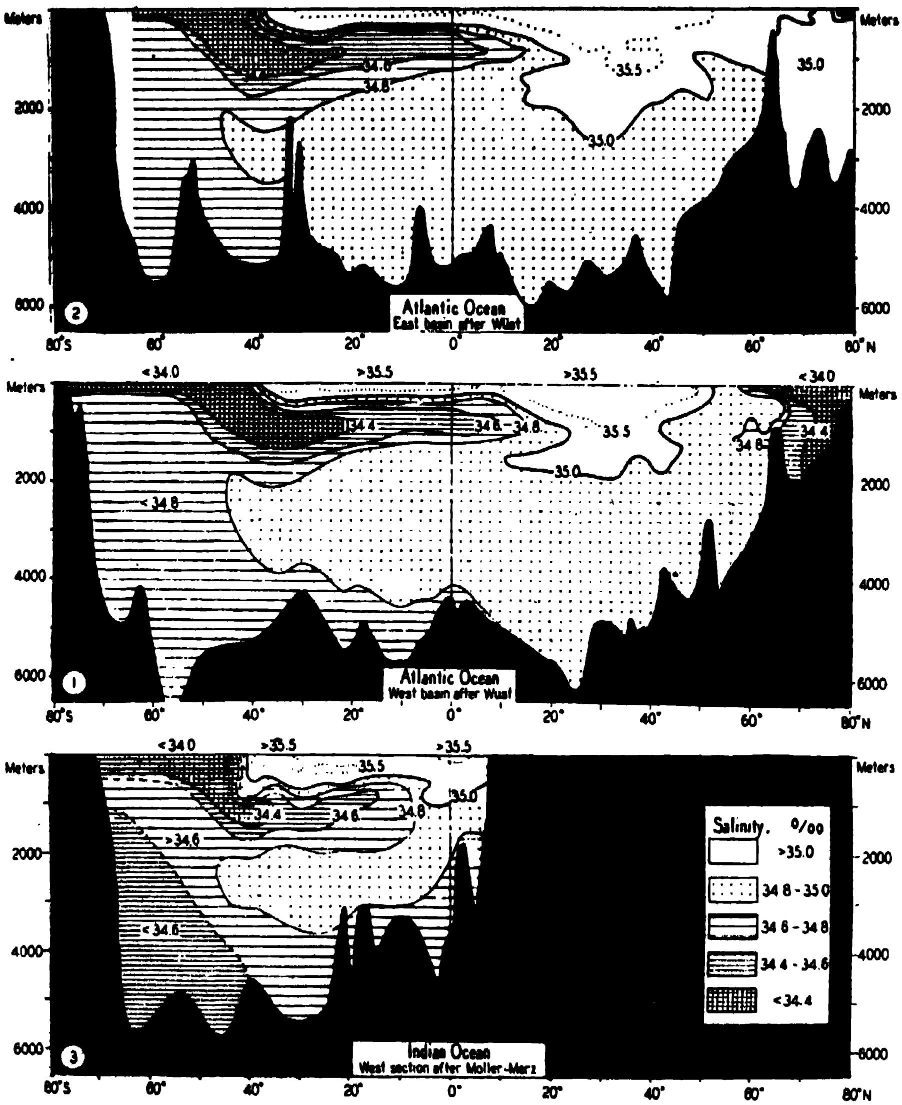
The deeper and bottom water in the North Atlantic is derived from several sources. One of these is the sinking of dense, warm water in the region of the northern subtropics. There is also sinking of water along the north polar front. Some Arctic water finds its way into the North Atlantic as cold bottom water, especially in the region of Davis Strait. One of the peculiarities of the North Atlantic Ocean is that there is a surface flow of less dense water into the Mediterranean through the Strait of Gibraltar, while there is along the bottom an outward flow, velocity over five knots per hour, of warm, dense water. The bottom water and the overlying deep water of the North Atlantic are therefore of composite origin. The combination of the various influences above mentioned causes the deep water in the North Atlantic to be of higher salinity and higher temperature than would otherwise be the case. This water pushes itself southward where, in general, it lies above the Antarctic water where the two come into contact, and below the intermediate water derived from the region of the south polar front. Its southward extent in the East Atlantic Trough is interrupted by Walfish Ridge. In the West Atlantic, where the northward extent of the Antarctic bottom water is not obstructed, a bottom temperature of 2° at a depth of 5,500 meters reaches to about 18° north latitude, whereas in the East Atlantic Trough, because of Walfish Ridge, water of a temperature of 2° does not reach farther north than the south side of Walfish Ridge, about 33° south latitude at a depth of about 3,600 meters. For the reasons above stated the deep and bottom water in the North Atlantic Ocean is derived from the north very largely by the downward sinking and subsurface intrusion of dense, relatively warm water.

The Indian Ocean. According to Lotte Möller there are in the Indian Ocean, between latitudes 5° and 40° S., four different kinds of water which, described from the surface downward, are as follows: (1) There is a subtropical surface layer with a salinity above 35.00°/oo and a temperature above 11° C. This water comes from the subtropical zones of maximum salinity on both sides of the Equator. It is underlain by (2) water of Antarctic origin which has a salinity of between 34.00°/oo and 34.70°/oo and a temperature between 8° C. and 2.5° C. (3) Under number 2 there is deep water which comes from the North Indian Subtropics and has a salinity of more than 34.75°/oo and is of higher temperature. (4) The bottom water which comes from the Antarctic and has a salinity between 34.50°/oo and 34.69°/oo with a temperature between zero and 1.5° C.

The semi-annual changes in the winds and the distribution of air pressure, because of their influence on surface gradients, produce changes in the direction of the deep currents, especially in the northwest Indian Ocean, but in the open ocean such changes are small.

Before leaving the account of the Indian Ocean, the effects of warm water of high salinity discharged from the Red Sea and the Gulf of Arabia should be mentioned. This water exerts an appreciable influence on the character of the water in the Indian Ocean.

The question of the exchange of water between the Indian and other oceans will now be considered. Lotte Möller has made suggestions regarding this



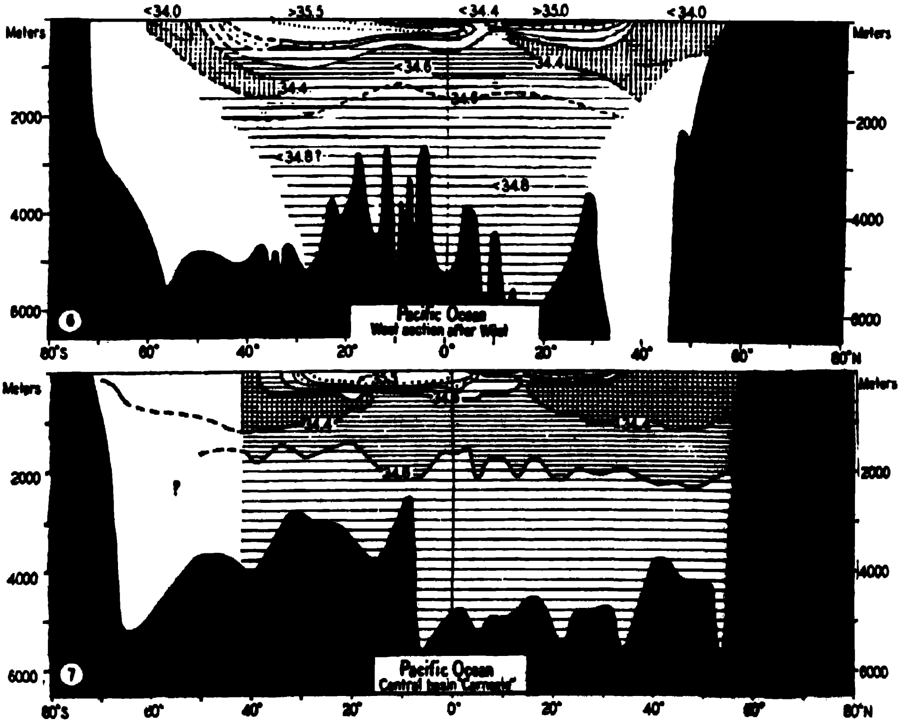
(UPPER)—ATLANTIC OCEAN, EAST TROUGH, SALINITY SECTION. AFTER WÜST. (MIDDLE)—ATLANTIC OCEAN, WEST TROUGH, SALINITY SECTION. AFTER WÜST. (LOWER)—INDIAN OCEAN, WEST PART, SALINITY SECTION. AFTER MÖLLER AND MERZ.

matter and they have been repeated by Wüst. According to Möller, in its upper 500 meters the Indian Ocean is filled with water of especially low density. The surface level therefore stands higher and accordingly there are gradient currents which are directed around the southern end of Africa into the Atlantic and south of Australia into the Pacific. Below 400 meters the pressure gradients along 40° S. latitude are directed from the Atlantic eastward toward the Indian Ocean and westward towards the Pacific, so that the West Atlantic represents a region of divergence, the West Pacific a region of convergence, of deep currents.

Along 55° S. latitude the pressure gradient is likewise directed from the Atlantic to the Indian Ocean. Accordingly, it can be postulated that within the Antarctic region, in so far as it belongs to the Indian Ocean, the Antarctic intermediate current flows toward the northeast, the deep current derived from the northwest toward the southeast, and, therefore, the water masses of the deep layers to a depth of 3,000 meters exhibit an interoceanic circulation. Below 3,000 meters the water masses in all of the oceans possess little difference in density, so that the distribution of the bottom water is dependent upon the configuration of the bottom.

The Pacific Basin. A brief summary of the principal conclusions of Wüst regarding the water circulation in the Pacific Basin is as follows:

In the west the boundaries of the troposphere are strongly marked and are pushed poleward as far as 55° S. latiture and 40° N. latitude, but in the east the troposphere is less developed and there it is meridionally very restricted. Since it has its greatest extent, both meridionally and vertically, in the west, especially in the southwest, the Pacific troposphere in its relations to the equator is quite asymmetrical. Corresponding to this structure, the warm water circulation of both hemispheres is asymmetrical. In a meridional direction it consists of a superficial spreading out of equatorial warm water masses of low salinity towards the poles as far as the subtropics and of an oppositely directed forward pressing of cooler, more highly saline water in the subtropical lower current. In the North Pacific this circulation is confined to a layer of water about 300 meters thick between latitudes 10° N. and 20° to 25° N. In contrast to this restriction, it shows extensive de-



(UPPER)—PACIFIC OCEAN, SALINITY, WEST SECTION. AFTER WÜST. (LOWER)—PACIFIC OCEAN, SALINITY, CENTRAL PART, *Carnegie* DATA. AFTER SVERDRUP.

velopment in the western part of the South Pacific, where the highly saline subtropical lower current can be followed in depths of about 200 meters through 35 degrees of latitude. The place of reversal of this asymmetrical warm water circulation lies in the West Pacific in 7° N. latitude, in the Central Pacific about 15° N. latitude.

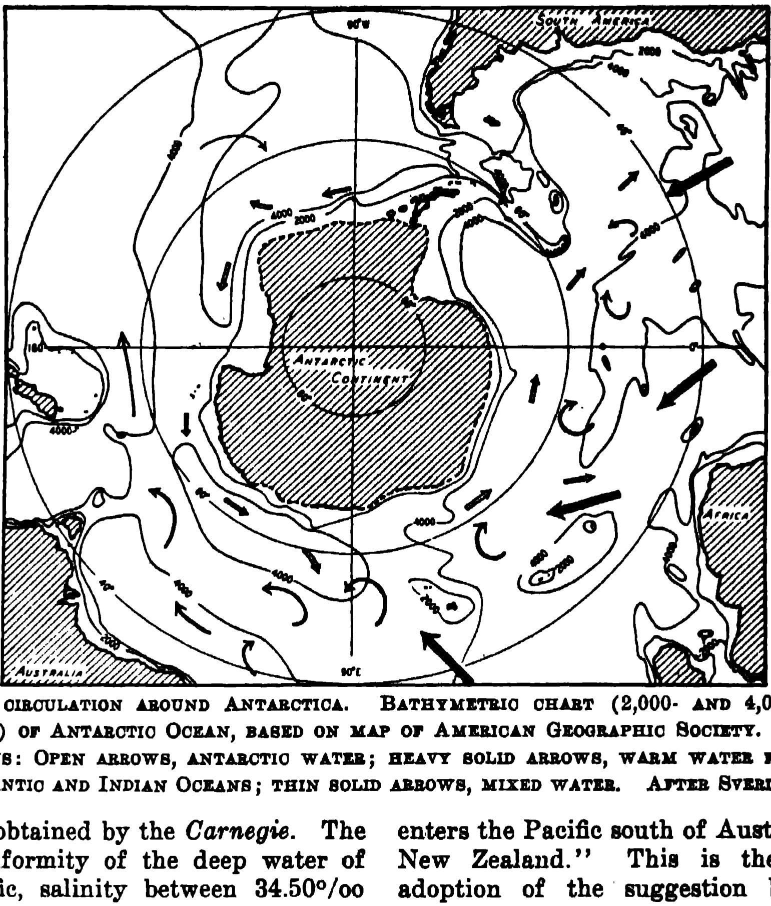
Regarding the cold water circulation the conclusions are that the water masses of the equatorial zone in the boundary regions of both intermediate streams, especially in the central part of the ocean, possess a tendency to sink and that here the source of the highly saline deep water should be sought. In the Atlantic the place of reversal for the stratospheric circulation is between 30° and 40° N. latitude, and with reference to it the circulation is quite asymmetrical. In the Pacific, in strong contrast, the stratospheric circulation possesses a nearly symmetrical structure. Two intermediate streams of nearly the same thickness conduct subpolar water from both sides to the equatorial zone, where it appears that the horizontal motion is transformed into a downward vertical motion. The place of reversal of this cold water circulation lies in the Pacific between 3° and 5° N. latitude.

On the other members of the stratospheric circulation, deep currents and bottom currents, there is only scant information. On the basis of compensation it seems necessary to assume that to the intermediate currents directed toward the equator there correspond highly saline deep currents directed toward each pole, that is, toward the south in the southern hemisphere and toward the north in the northern hemisphere. Indications of this are found in the disturbed temperature distribution in the section along the central part of the Pacific in depths between 1,500 and 2,500 meters.

Wüst suggests other possibilities for the formation of these highly saline water masses. He calls attention to the high salinity of the lower layers north of the Fiji Basin, where at a depth of 2,000 meters at Planet station 55 the salinity is 34.79°/oo. This excess of salinity might be expected to cause between 1,000 and 2,000 meters an excess of density to which compensating currents should correspond. The confining basins east of Australia may contribute to the formation of highly saline waters, but what their effect may be can be judged only after the acquisition of new observational data. Wüst also calls attention to the suggestion of Lotte Möller with regard to the Indian Ocean, which she shows contains in these latitudes, at depths between 2,000 and 3,000 meters, water of a salinity higher than 34.70°/oo, in the west even as high as 34.80°/oo, and that we must therefore reckon with a zonally directed deep current which carries highly saline water from the Indian to the Pacific Ocean.

Before considering the results of the recent work of the *Carnegie* and of those who have been connected with the preparation of the scientific reports on them, two aspects of Wüst's interpretation of the sources of the stratospheric water in the Pacific should be emphasized. One of these is the significance that he attached to the reversal of the two intermediate streams which conduct subpolar water to the equatorial zone and to his inferences that the horizontal motion between latitude 3° and 5° N. is transformed into downward vertical motion. The other is that he has considered the suggestion of Lotte Möller regarding the Indian Ocean as a possible source of the deep water in the Pacific Ocean.

H. U. Sverdrup has recently published an article entitled "The origin of the deep water of the Pacific Ocean as indicated by the oceanographic work of the *Carnegie*." This article deals altogether with the stratospheric water. A new section for the Central Pacific is based on



OCEANIC CIRCULATION AROUND ANTARCTICA. BATHYMETRIC CHART (2,000- AND 4,000-METER ISOBATHS) OF ANTARCTIC OCEAN, BASED ON MAP OF AMERICAN GEOGRAPHIC SOCIETY. LEGEND FOR FLOWS: OPEN ARROWS, ANTARCTIC WATER; HEAVY SOLID ARROWS, WARM WATER FROM THE ATLANTIC AND INDIAN OCEANS; THIN SOLID ARROWS, MIXED WATER. AFTER SVERDRUP.

the data obtained by the *Carnegie*. The great uniformity of the deep water of the Pacific, salinity between 34.50°/oo and 34.60°/oo, and a temperature between about 1° and 3° C., is most impressive. Sverdurp shows that this uniform water can not originate by the sinking of surface water between latitudes 3° and 5° N., nor can it be formed in the southern part of the Antarctic and thence flow as a bottom current toward the north and return toward the south at depths of about 3,000 meters, because the temperatures are too high. Sverdrup says that "it seems more probable to assume that the deep water which fills the Pacific is formed north of the Antarctic continent in the Atlantic, and especially in the Indian Antarctic Ocean by the mixing of deep water coming from the north and true Antarctic water coming from the south, and that this water enters the Pacific south of Australia and New Zealand." This is the virtual adoption of the suggestion by Lotte Möller, which was repeated by Wüst, but who inclined to the interpretation that has been invalidated by the work of the *Carnegie*.

Sverdrup discusses the effect of the Antarctic Archipelago on the movement of Antarctic water into the South Pacific. The water movements around the periphery of the Antarctic Continent would tend to be from the east toward the west, but the deflecting effect of the earth's rotation must be taken into account. Sverdrup correctly remarks that

> the extension of the Antarctic Archipelago towards the north prevents this water from continuing into the Pacific when flowing west, and the bulk of the water must, therefore, enter the Atlantic Ocean. The restricted communication between the Pacific and the Atlantic seems thus to account for the fact that the

> returning deep current carrying warm water of high salinity toward the south is most conspicuous in this (the Atlantic Ocean). This returning current must also be deflected toward the left, which in this case means to the east, and the returning current from the Atlantic must therefore enter the Indian Ocean, as pointed out by L. Möller. In the Indian and Atlantic Oceans we thus find a flow of cold water of low salinity towards the northwest and a flow of warm water of high salinity toward the southeast. Considerable mixing of these different types of water must take place and increase of the salinity of the cold water from east to west and the decrease of the salinity of the warm water in the opposite direction may be regarded as the results of such mixing. The mixing processes appear to be most pronounced in the eastern part of the Indian Antarctic Ocean where at depths below 2,000 meters a great basin is filled with water of temperature between 1° and 3°, and salinity between 34.6°/oo and 34.8 per mille. This water is nearly of the same type as the deep water of the Pacific. The uniform character of the water seems to be more pronounced south of Australia where the temperature-observations indicate conditions which are very similar to those in the Pacific but the salinity-values are unfortunately lacking from this section.
>
> All the available data point strongly in the direction that water of the same type as the deep water of the Pacific is formed in the eastern part of the Indian Antarctic Ocean, and that the origin of the deep water of the Pacific has to be sought there. This deep-water probably enters the Pacific through the opening south of New Zealand, but the inflow must be very slow and the deep water circulation of the Pacific correspondingly slow.

Mention should here be made of a very recent publication by M. Uda in which he shows that off the east coast of northern Honshu and Hokkaido cold water of the Oyashiwo sinks beneath the warm water of the Kuroshiwo. These observations bear upon the problems of the source of a part of the intermediate water in the Northwest Pacific and of the larger quantities of dissolved oxygen in the Northwest than in the Northeast Pacific.

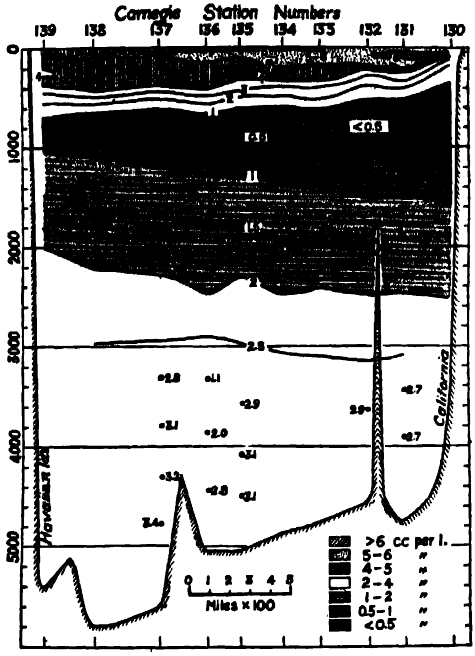
After having briefly outlined the general scheme of circulation for the different ocean basins in accordance with the most recent interpretations, the effect of this circulation on the habitats of marine organisms will be briefly considered.

OXYGEN IN THE SEA

Although the study of the vertical and horizontal distribution of oxygen in the different oceans has received attention for a number of years it is only recently that it has become possible to consider the subject in a comprehensive way. The work of the *Meteor* in the Atlantic, that in connection with the *Carnegie* and the Scripps Institution in California, that of K. Ito in Japan, and that of J. Schmidt on the *Dana,* are particularly significant. Recently Moberg has summarized the information for the Pacific and compared conditions with those in the Atlantic. Subsequent to Moberg's publication, K. Ito has published an account of the results that he obtained in the southwest part of the North Pacific, and the results of the *Dana* have appeared in print. According to Moberg, four layers of water can be recognized in the Eastern Pacific: (1) One near the surface in which the oxygen content is high, (2) an immediately lower zone in which photosynthesis is active and there is the maximum quantity of oxygen, (3) a zone in which the oxgyen content decreases to a minimum, (4) a deep layer in which the amount of oxygen slowly increases with depth but is always less than that in the surface layer.

The amount of oxygen in the surface waters along the coast of southern California is a function of the temperature, as Moberg has shown. The water is virtually saturated, but the quantity varies with the temperature according to the well-known laws of the solubility of gases in liquids.

The general oxygen relations between San Francisco and Honolulu have been summarized by Moberg. The minimum value in the minimum layer is 0.2 ml. per liter. At one station, *Carnegie* station 151, approximately latitude 12° N., longitude 138° W., the amount of oxygen



SECTION, SAN FRANCISCO TO HONOLULU. SHOWING DISTRIBUTION OF OXYGEN, ML. PER LITER. AFTER MOBERG, *Carnegie* DATA.

was virtually nil and this condition prevailed from a depth of 100 to 400 meters.

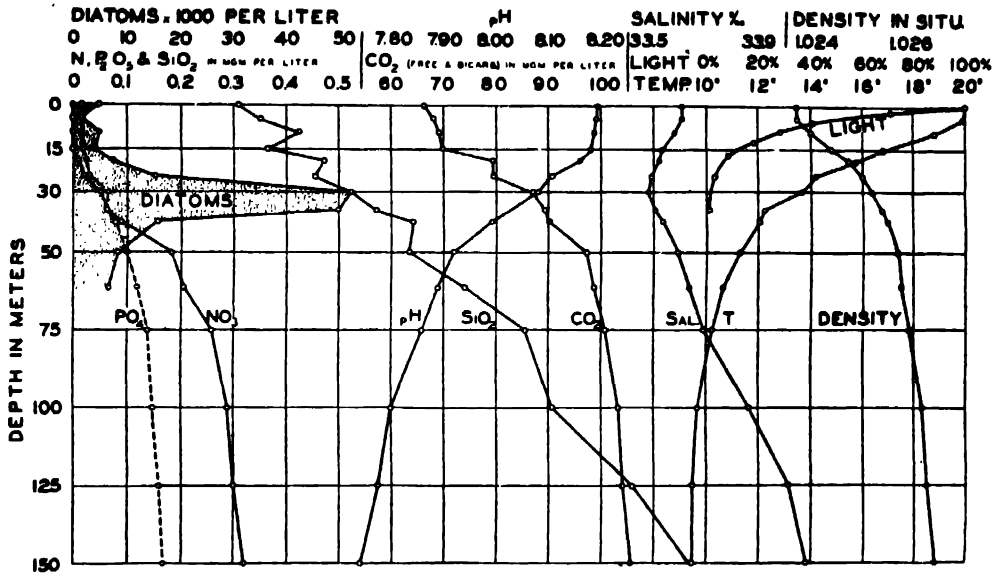
Moberg has compared conditions in the Pacific with those in the Atlantic. There is in the Atlantic a minimum layer somewhat similar to the minimum layer in the Pacific, but the amount of oxygen is greater in the Atlantic than in the Pacific. Below the minimum layer the amount of oxygen in the Atlantic is decidedly greater than in the Pacific. This difference between the oxygen distribution in the Atlantic and the Pacific is significant for a number of reasons, one of which is the bearing that it has on the source of the deep water and the bottom water in the Pacific, and another is because of the influence that it may exert on the vertical distribution of organisms.

According to K. Ito, there is in the Western Pacific no such oxygen deficiency as is found in the Central and Eastern Pacific. Explanations for this condition are at hand, but they will not be given here. The results of the *Dana* are in accord with the conditions already indicated.

Because of the oxygen deficiency over so great an extent of the Pacific, Moberg concludes that the deep water of the Pacific has lacked contact with the atmosphere during a longer period than has the deep water of the Atlantic, and he is of the opinion that most of the deep water of the Pacific enters that ocean by way of the southern Indian Ocean. Furthermore, he expresses the opinion that because the water in the South Pacific below 2,000 meters contains an appreciably greater quantity of oxygen than that at corresponding latitudes of the North Pacific a northward flow is indicated. In the North Pacific, however, since the oxygen content below 2,000 meters is virtually constant from the equator to latitude 37° N., it appears improbable that appreciable quantities of water flow northward across the equator in the region for which observations are available.

DISSOLVED NUTRIENT SALTS

Moberg has made a special study of the variations in the amounts of nutrient salts dissolved in the sea water of the Pacific, especially in the region of southern California, and has published one paper which is of particular significance in this connection. It is entitled "The interrelation between diatoms, their chemical environment, and upwelling water in the sea off the coast of southern California." In this paper he shows that between depths of 30 and 50 meters there is, according to counts by W. E. Allen, maximum abundance of diatoms, and above those depths there is decrease in the quantities of PO_4, NO_3, and CO_2, and increase in pH, intensity of light, and temperature. The SiO_3 decreases in quantity toward the surface, but it is peculiar in that there is no significant



SECTION OFF LA JOLLA, CALIFORNIA. SHOWING SUBSURFACE DISTRIBUTION OF SOLUTES. AFTER MOBERG.

change in the trend of its amount above 50 meters. The lower limit of the maximum abundance of diatoms coincides closely with Richardson's measurements of the depth of penetration of light in the region, which is that, at a depth of 50 meters, 98 per cent. of the light of the wave lengths to which the photoelectric cell used by him was sensitive, had already been aborbed. The depletion of PO_4, NO_3, and CO_2 may be attributed to the activity of pelagic plants. The section shows that below a depth of about 50 meters there is an abundant supply of nutrient salts needed by plants. A continuous supply of such substances is maintained by upwelling, which has been the subject of detailed investigations by G. F. McEwen. This work of McEwen's serves as a logical foundation for the later work of Moberg on the distribution of nutrient salts in the sea water of the region.

Moberg, Seiwell, Graham and Paul have published a paper entitled "Phosphate-content of the Surface-water in the Pacific as Related to the Circulation." This paper can not be summarized in this lecture, but it may be pointed out that eastward from Japan to longitude about 130° W., and between latitudes 40° and 10° N. there is in the surface waters of the Pacific a great deficiency in PO_4, the amount being 10 mg or less per cubic meter, and in places there is less than 5 mg per cubic meter. The largest amounts of phosphate are found north of latitude 40° N., off the west coast of the United States, and off the northern part of the west coast of South America and westward from there as far as about longitude 180°. Moberg correlates the surface distribution of phosphate with the circulation of the ocean waters.

SURFACE TEMPERATURES

The first comprehensive studies of surface temperatures of the ocean appear to have been made by Sir John Murray. In one of his papers, entitled "On the Distribution of the Pelagic Foraminifera at the Surface and on the Floor of the Ocean," published in 1897, he reiterates conclusions previously expressed, and says:

The surface of the sea may be grouped into five great zones, *viz.:* (1) A nearly continuous equatorial zone, where the temperature is high and the range throughout the year does not exceed 10° F. This zone includes all the principal coral reef regions. (2 and 3) Two polar zones, where the temperature is low and the annual range does not exceed 10° F. In these zones there are relatively few lime-secreting organisms. (4 and 5) Two regions lying between the equatorial zone and the two polar zones, where a wide range of temperature occurs between the different seasons (annual range amounting to as much as 52° F. in some places). In these temperate regions the secretion of carbonate of lime appears to be much more active in the warmer than in the colder months. It thus appears that the most favorable conditions for lime-secreting organisms are met with in the warm, equable tropical waters of the ocean, and here as a matter of fact we find the greatest development of corals, and the largest number of lime-secreting pelagic organisms. In the polar areas and in the cold water of the deep sea, there is, as is well-known, a feeble development of all carbonate of lime structures in marine organisms.

It should be pointed out that because of the surface circulation of the ocean off the east sides of the continents warm water is carried many degrees northward, that is, until the water comes within the influence of the west wind drifts. This means that, except immediately along the shores where there may be southwardly directed cool currents, conditions are favorable for the growth of organisms that need rather high temperature. In the North Atlantic it is well known that the gulf stream drift continues to the vicinity of the British Isles and that some of its water extends farther toward the north. This warm water tempers the climate of all of northwestern Europe. In the Pacific Ocean the warm waters carried by the Japan current or drift extend eastward to the Alaskan region and then southward until they are off the northwest coast of the United States. This warm water which comes from the west side of the Pacific tempers the climate of the western side of the North American continent from Alaska southward as far as Oregon and California.

The effect of the winds along the west coast of Africa and along the west coast of North and South America in low temperate and subtropical latitudes has already been indicated. These winds, because they blow either along shore or from the land toward the water, produce surface movements of water at 45° to the right of the wind in the northern hemisphere and 45° to its left in the southern hemisphere. To compensate for the water which has been pushed away from the shore there must be an upwelling of cold water, and, as we have already seen from the discussion of the distribution of chemical substances dissolved in sea water, this cold water carries with it substances that are needed for the nutrition of marine plants.

Because of warm water on the west sides of the oceans, reef corals thrive through many degrees of latitude; but on the east sides of the oceans, because of upwelling cold water, they are scarce or absent.

SUBSURFACE DRIFT OF THE WATER IN THE GULF OF ALASKA

In connection with his study of the distribution of halibut eggs, W. F. Thompson, the director of scientific research for the International Fisheries Commission, needed to know the possibility of the subsurface drift of halibut eggs which are bathypelagic, that is, they float in the water below the level of the surface. In order to find out what the possibilities might be Thompson sought the assistance of McEwen. Thompson acquired the necessary information on the temperature and salinity of the water in the Gulf of Alaska at appropriate depths along several section lines. From the information thus obtained McEwen was able to calculate the relative movements of the water, and he found that there was a rather slow but rather steady subsurface drift toward the northwest and west. This gave to Thompson the information that he needed to understand the drift of the halibut eggs.

DEPTH OF PENETRATION OF LIGHT INTO SEA WATER

This subject has been studied by numerous investigators, among whom may be mentioned Helland-Hansen, Poole and Atkins, Shelford and Gail, and Burt Richardson. The results obtained by Helland-Hansen by means of a photometer will be summarized. The depth of penetration of light is influenced by latitude. According to Helland-Hansen there would be the same intensity for rectilinear rays, as follows:

In 33° N. latitude at about 800 meters' depth.
In 50° N. latitude at about 500 meters' depth.
In 67° N. latitude at about 200 meters' depth.

The results of experiments made off the Azores on the *Michael Sars* were as follows:

100 meters, red rays weak, blue and ultra-violet strongest.

500 meters, blue and ultra-violet distinctly visible.

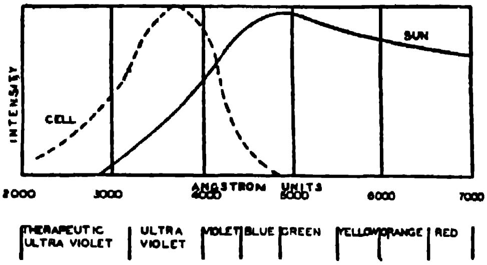
1,000 meters, ultra-violet perceptible.

1,700 meters, no trace of light.

Burt Richardson has summarized and tabulated the results of other investigators, as well as making additional measurements, himself, of the depth of penetration of light. The following is an abstract of a paper by Richardson entitled "The Photoelectric Measurements of the Penetration in Sea Water of Light (Wave-Lengths 2,900 to 4,800 Ångström Units)":

Shelford and Gail in Puget Sound, Washington, and Poole and Atkins in the English Channel off Plymouth, England, determined quantitatively the penetration of light for various depths in sea water by the photoelectric cell method using electrical circuits with high sensitivity. Application of their data and conclusions to an entirely different water, such as the Pacific Ocean near San Diego, California, would not be justified. Therefore, during the summer of 1930, an area seven miles off the coast of La Jolla (City of San Diego), California, was studied by submerging a Burt photoelectric sodium-vacuum cell to various depth levels in the ocean.

The results indicate that about 21 per cent. of the light (of wave lengths 2900 to 4800 Ångström units, to which the photoelectric cell is sensitive) is absorbed by the first ½ centimeter of water, that about 50 per cent. is absorbed by the first meter, 88 per cent. by the first 10 meters, and over 98 per cent. is absorbed by 50 meters of sea water.



GRAPH COMPARING SENSITIVITY OF PHOTOELECTRIC CELL USED BY RICHARDSON AND SUNLIGHT. AFTER RICHARDSON.

Richardson has prepared tables giving the results of previous workers, as well as of himself. They are as follows:

PENETRATION OF LIGHT INTO SEA WATER. ENGLISH CHANNEL, PLYMOUTH, ENGLAND. (POOLE AND ATKINS.)

Cell used, Kunz Potassium-hydride; sensitive to wave-lengths, 4,050 Ångströms maximum.)

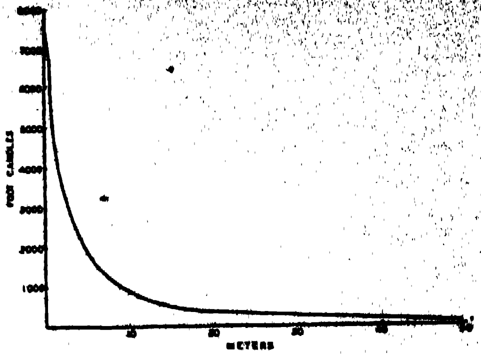
Date	Depth	Intensity in foot-candles	Per cent. light	Absorption coefficient
1927 9/7	Surface dry	8,170	100	
				.0035
	5	1,412	17	
				.0029
	10	319	4	
				.0028
	15	76	1	
9/12	Surface dry	4,190	100	
				.0036
	5	1,430	34	
				.0018
	10	581	14	
				.0028
	15	251	6	
				.0014
	20	115	3	
10/3	Surface dry	5,210	100	
				.0027
	5	1,330	26	
				.0010
	10	837	16	
				.0011
	15	493	9	
				.0012
	20	256	5	
				.0019
	25	118	2	

PENETRATION OF LIGHT INTO SEA WATER. PUGET SOUND, WASHINGTON. (SHELFORD AND GAIL.)
(Cell used, Kunz Potassium-hydrogen; sensitive to wave-lengths, 4,200 to 5,000 Ångströms.)

Depth	Intensity in foot candles	Per cent. light	Per cent. wet	Absorption coefficient
Surface dry	8,650	100		
Surface wet	6,550	76	100	
				.00234
5	1,990	23	31	
				.00174
10	830	10	13	
				.0006
25	335	4	5	
				.00049
35	204	2	3	
				.00031
50	129	1	2	

PENETRATION OF LIGHT INTO SEA WATER. OFF LA JOLLA, CALIFORNIA, AUGUST, 1930. (BURT RICHARDSON.)
(Cell used, Burt Sodium-vacuum; sensitive to wave-lengths, 2,900 to 4,800 Ångströms.)

Corrected depths	Per cent. transmitted	Per cent. transmitted from ½ cm water	Absorption coefficient /cm
Surface dry	100		
Surface wet ½ cm	77	100	
			.0023
5 cm	24	31.9	
			.0015
10	11.5	14.9	
			.0010
15	7.1	8.2	
			.00096
20	5.2	6.8	
			.00042
25	4.2	5.5	
			.0005
30	3.3	4.3	
			.0005
35	2.6	3.4	
			.0003
40	2.2	2.9	
			.0004
45	1.8	2.4	
			.0003
50	1.6	2.1	



DEPTH OF PENETRATION OF LIGHT, WAVE-LENGTHS 2,900–4,800 ANGSTRÖMS, OFF LA JOLLA, CALIFORNIA. AFTER RICHARDSON.

It is Richardson's intention, with the assistance of the Southern California Telephone Company, to select a series of photoelectric cells which will be sensitive to other wave-lengths of light than those already studied by him. Although the study is not yet complete, important information has been obtained by the series of investigators as regards the depth of penetration of certain wave-lengths of light, and they are of value in gauging depths to which the photosynthetic activity of plants is effective.

From available present knowledge it is obvious that photosynthesis is confined to relatively shallow depths, probably to 50 to 60 fathoms, 90 to 110 meters, in the tropics, and to shallower depths in latitudes nearer the poles. Professor Stanley Gardiner places the maximum depth of nullipores at 60 fathoms.

CONCLUSIONS

For the circulation of the water in the Pacific we have, as a result of the work of many organizations and more numerous individuals, a working hypothesis. This hypothesis should be tested in all its many ramifications and it should be dealt with according to the findings. Sir Douglas Mawson's expedition in the Antarctic Indian Ocean will certainly throw more light on the interrelation of the water in the Indian Ocean with that of the Atlantic on one hand and that of the Pacific on the other. For the Pacific basin as a whole there is need for accurate investigation of the water movements according to the modern methods of dynamical oceanography. These methods can not be reviewed here but they are known to all workers in the field of dynamical oceanography. The observations and determinations must be on an extensive scale and, to serve the purpose for which they may be made, they must be precise. Until now only beginnings have been made in the United States, Japan and the Netherlands Indies.

The problems of the chemistry of the ocean will be discussed in this symposium by Messrs. Thompson and Moberg. As yet we have only samples of what may be discovered. These samples excite our curiosity and should stimulate us to make greater efforts to attain a fuller knowledge and better understanding of this complex and fundamental aspect of the Pacific Ocean.

Our knowledge of the depth of penetration of light into sea water is steadily advancing, but it is still far from being adequate.

Although the fundamental elements of the marine environment are physical and chemical, if research stopped with the results obtained in those fields, we should have only partial knowledge of the ocean. There are the organisms and the manifold geologic processes, organic and inorganic, there operative.

The solution of the different kinds of problems stated or indicated requires extensive operations at sea, as well as laboratory work. There has been great activity within the Pacific during the past few years and accounts of it are available in several publications, but there remain areas for the exploration of which there are still no assured provisions, and numerous special problems have been touched scarcely or not at all. Since the chemistry of the sea, organisms as biochemical agents, and the geologic significance of oceanographic research will be discussed by other participants in this symposium, the remainder of my remarks will deal only with completing the exploration of the Pacific basin.

At the third Pacific Science Congress in Tokyo, in 1926, in compliance with an invitation from the President of the Congress, I read a paper, "International cooperation in oceanographic investigations in the Pacific," and at the fourth congress in Java, in 1929, I presented a paper, "Suggestions for oceanographic exploration of the Pacific." The areas in the Pacific for the exploration of which provisions are especially needed are (1) the region adjacent to Antarctica, (2) the area from the Equator to latitude 20° S. and between meridians 130° and 170° W.; and (3) very nearly the whole of the Eastern Pacific from the coast lines of North and South America to a distance of about 2,000 miles offshore. At present we are chiefly concerned with the last-mentioned area.

Before the lamentable destruction of the *Carnegie* it was expected that the Scripps Institution would take over that vessel for two-years' continuous work in the area designated. That plan is now impossible of fulfillment and other means of doing the work must be sought. Some data are already available, but not all are of the required degree of accuracy. Notwithstanding that defect, an endeavor has been initiated at the Scripps Institution to utilize the available data for constructing a longitudinal section for the Eastern Pacific similar to the sections that have already been prepared for the Central and Western Pacific. It is fortunate that the University of Washington has undertaken organized oceanographic research. It and the International Fisheries Commission, perhaps with the assistance of the Canadians and of other organizations in the United States, may undertake investigations in the northern part of the area. The Scripps Institution hopes to get a vessel, and, if it does, it intends to conduct consecutive work in the area bounded by a line from San Francisco to the Hawaiian Islands, thence southward to the Society Islands, and thence eastward to the South American coast. Although the investigations indicated would not in themselves give a complete picture of conditions in the Pacific, they would make invaluable contributions toward completing that picture, especially after the results have been coordinated with results obtained by others. Perhaps others might be stimulated to fill the gaps for the region adjacent to Antarctica and the Tropical Central Pacific south of the Equator.[2]

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[2] Thanks are extended to Mr. John A. Fleming, acting director of the Department of Terrestrial Magnetism, Carnegie Institution of Washington, for photographs of the drawings which are here reproduced as Figs. 3 to 9, inclusive. All the illustrations used in this paper have previously been published, except Figs. 9, 11 and 12.

THE CHANGED OUTLOOK IN REGARD TO POPULATION, 1831-1931[1]

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TIMES change, and economic theories change with them. We need no longer be ashamed of the fact, as we used to be inclined to be in the old days, when our colleagues in other sections of the association professed to despise us for disagreeing among ourselves and perpetually overthrowing conclusions arrived at by our predecessors. We hear less now of the certainty and finality of the other sciences, and can face their exponents unabashed, confident that theories may be useful for leading us on towards the truth without being immutable and exempt from revision.

I think that the biggest change made in economic theory during the last hundred years is to be found in the treatment of the subject of population. In 1831, Malthus was still alive, and quite unrepentant for the shock he had given the public thirty-three years earlier by his "Essay on the Principle of Population as it Affects the Future Improvement of Society." No one, it is true, any longer attached much importance to his doctrine of the inherent incompatibility of the ratios in which it was possible for population and food to increase, but the disfavor with which he regarded what he considered the natural tendency of population to increase was shared by most of the economists of the orthodox school, who had adopted the theory of diminishing returns to agriculture which was evolved in England from the local conditions of the very "short period" of the Napoleonic war.

That theory, not as now taught in a form which makes it innocuous, but as taught in the early years of the nineteenth century, purported to show that the natural limitation of fertile and well-situated land must necessarily mean that the more numerous the people, the more difficult it must be for them to feed themselves. It was admitted that there were counteracting circumstances, summed up as "the progress of civilization," which, in fact, had throughout history prevented the growing population of the civilized world from actually finding it more difficult to feed itself, but these circumstances were regarded as making only temporary headway against the general tendency, and not, like it, as being a law of nature. J. S. Mill, in his "Principles of Political Economy with Some of Their Applications to Social Philosophy," which, though not made into a book until seventeen years after, was really thought out before 1831, and represents the ideas of 1800 to 1830 better than any other work, even ventured to assert that though the people of his time were better off than the people of a thousand years before, they would have been still better off if the increase of population had been less.

The economic history of the hundred years has tended to bring about a very complete reversal of economists' view of this matter.

The hundred years began with developments which threw great discredit on the fundamental assumption of the old school that the extension of human occupation of land necessarily meant that less fertile and less well-situated land must be occupied as numbers grew. It was easy for men who saw arable cultivation creeping over barren hills in England and stony "bogs" in Ireland to believe in that theory when Chicago was a collection of Indian huts, and Broadway, New York, a rough cart track to a farm, but the application of steam to ships and railways enabled mankind to extend easily over an immense area of land more fertile than much of what was occupied before. And as for situation, not only did the improvement in transport, coupled with the violations of natural geography involved in the cutting of the great ship canals, bring the "more distant" lands nearer the "market," it also eventually brought "the market" to the "more distant" lands.

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[1] A lecture delivered at the centenary meeting of the British Association for the Advancement of Science, London, September, 1931.

So we no longer think of the first cradle of the human race (or the first cradles of the human races if there are more than one) as the most fertile and well-situated spot (or spots) from which men have gradually been forced outwards. You all probably know the opinion of the British Army in Mesopotamia, expressed by the sergeant who was told by an officer that he was now on the very site of the Garden of Eden: "Well, Sir, all I can say is that if this was the Garden of Eden it's no wonder the twelve apostles mutinied." Though the sergeant was evidently not a well-read man, the change of view had reached even him.

Later in the hundred years, scientific discovery in various directions has led to a complete change of emphasis in regard to the importance of what the old economists used to call "improvements." The old economists thought of hedges and ditches, drains, and a few other trifles of that kind which would enable corn to be more easily produced from European fields, and just a little of better breeding of cattle and sheep. These were things which might, they believed, interrupt for a time, now and then, the general downward drift of the returns to agricultural industry, but could not do more than that. Modern science has changed our outlook. We set no bounds to the possibilities of improvement. We expect to make unwholesome areas healthy, and to modify vegetable as well as animal products so that they will better serve our needs. Primitive mankind presumably fought and killed some of the now extinct carnivora; advanced mankind fights and will kill the locusts and the smaller insects which have hitherto prevented much use being made of some of the most fertile areas of the world. It was not an economist who, only a few years ago in the presidential chair of the association, foretold that very soon the world would be suffering from a shortage of wheat.

Thus, even if we still expected population to increase very rapidly, we should not believe, as J. S. Mill did, that it "everywhere treads close on the heels of agricultural improvement, and effaces its effects as fast as they are produced."[2] But in fact, Cotter Morison's cry, made only a generation ago, that all would be well if only we could stop for a few years "the devastating torrent of babies" now seems grotesque, for we do not now expect rapid increase of population to continue much longer, even if it becomes progressively easier to obtain subsistence.

The approach of reduction in the rate of growth of population began to show itself in England in the second half of the 1871–80 decade, when the annual number of births became nearly stationary after the rapid increase recorded down to 1876. But the public takes little notice of the supply of people furnished by the births. Just in the wooden way in which illiterate farmers and unbusinesslike old ladies look at their balances at the bank, so the public looks at the censuses. The census of 1881 showed an increase of 14.36 per cent. in the decade, which was higher than that shown by any of the censuses except those of 1821 and 1831, which were probably unduly swollen by the diminishing incompleteness of the enumerations. In 1881–91, in spite of high emigration, the rate of increase only dropped to 11.65 per cent., so rapid increase of population was still regarded as the normal thing which every one should expect. The Royal Commission on the Water Supply of the Metropolis in 1893 deliberately rejected the reasonable suggestion that the rate of increase in Greater London might continue to fall as it had already begun to do, and relying on a continuance of observed increase, put the probable population in the present year, 1931, two and three quarter millions more than the recent census has shown it to be.

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[2] "Principles," Bk. IV, ch. iii, § 5.

But I had noticed that the old rapid increase in the annual number of births seemed to have come to an end, and working on the ages of the people as recorded in successive censuses, I put before this section of the association, at its meeting in Ipswich in 1895, a paper (subsequently published in the *Economic Journal* for December in that year) in which I estimated the number of persons who would be living at each census up to that of 1951 on the assumption that migration, mortality and the absolute number of births (not the rate) remained stationary. I found that on these hypotheses the population of England and Wales would stop increasing during the present century, and would have only a trifling increase after 1941. The paper suggested that this was, at any rate, not improbable.

Hostile critics derided what they called my "prophecy," and for some time events were unfavorable to me. Emigration fell off enormously, mortality decreased, and the births increased slightly, so that the census of 1901 showed an increase of 12.17 per cent. in the decade, the absolute increase of three and a half millions being the largest recorded. But the situation was not fundamentally altered, since the increase of births was due entirely to the drop in emigration, which had caused a larger proportion of persons of parental age to remain in the country. In the *Fortnightly Review* of March, 1902, I returned to the charge with an article on the "Recent Decline of Natality in Great Britain," in which, using a method of weighting the annual numbers of marriages by their proximity to the births recorded for each year—a method which seems to have been beneath the notice of the mathematical statisticians of that period—I was able to show, I think, conclusively, that the number of children resulting from each marriage was falling steadily and rapidly, and insisted with more emphasis than before on the "considerable probability of the disappearance of the natural increase of population—the excess of births over deaths—in Great Britain within the present century."

The decade 1901–11 was indecisive; the ratio of increase was smaller than in any of its ten predecessors, but the absolute amount of increase just topped that of 1891–1901, and the number of births till 1908 or 1909 seemed to indicate some recovery of natality. But this was illusory. Even before the war the births had got down again to the level of 1876. The war sent them tumbling down to about three quarters of that number, and now, after a wild but very short-lived recovery when the army returned from abroad, they seem inclined to settle at the war figure—three quarters of the number attained more than fifty years ago when the total population was twenty-six millions instead of forty millions, as it is now. The ratio of births, legitimate and illegitimate, to my weighted figure of marriages was just over 4½ fifty years ago, fell gradually and steadily to 3¼ before the war caused it to collapse.

It was commonly supposed by many of those to whom percentages serve rather to hide than to expose the facts on which they are based, that the diminution of births was being counterbalanced by the decline of infant mortality. It is true of course that diminution of infant mortality mitigates the effect of decline of natality, but the degree in which it can do so obviously decreases as the rate of infant mortality falls. When that rate is 500 per thousand, as it probably was here in the reign of Queen Anne, and may be still in great parts of Africa, a cutting down of births by 25 per cent. can be counteracted completely by a drop of one third in the infantile mortality rate. But when the infant mortality rate is down to 100 per thousand, it would have to fall to nothing at all in order to counteract a decline of only 10 per cent. in the number of births. In fact, the rate has fallen in England and Wales from about 140 to about 70 in the fifty years from 1881, and this drop to one half only balances about one fifth of the decline in the number of births.

Though there were eminent dissentients only a few years ago, statisticians are now agreed that in the absence of some great and unexpected change, the increase of population in England and Wales will come to an end at a very early date. Even the lay public has been to some extent enlightened and rather shocked by the recent census announcements that the population of Scotland has actually decreased in the ten years, and that of England and Wales has increased only 2,061,000, as against 3,543,000 in the ten years from 1901–11, though the emigrants have been 324,000 less.

The same change is observable in some degree in other Western European countries and our own oversea offshoots. The cause of it—birth control—will doubtless in time affect the rest of the world, so that while we may expect considerable increase—even an increase much more rapid than at present owing to decrease of huge infant mortality—to take place among the more backward peoples for another half-century at least, there is no reason whatever for expecting the population of the world to "tread close on the heels of subsistence" in the future, even if it may be correctly regarded as having done so in the past.

This change in our expectations involves many changes of emphasis, both in the theory of production and in that of distribution.

Two of them are perfectly obvious. First, the need, which J. S. Mill and most of his contemporaries and immediate predecessors felt so strongly, for insisting on the due restriction of population, has completely disappeared in the Western countries. Economists do not now require to talk as if the first duty of men and women was to refrain from propagating their race. Secondly, the need for insisting on the desirability of saving has become less pressing. A rapidly increasing population requires a rapidly increasing number of tools, machines, ships, houses and other articles of material equipment in order merely to maintain, without improving, its economic condition, while at the same time the maintenance of a larger proportion of children renders it more difficult to make the required additions. To a stationary population saving will still be desirable for the improvement of conditions, but it need no longer be insisted on as necessary for the mere maintenance of the existing standard.

But there are other changes of equal importance which are more likely to be overlooked. One is in regard to the weight which we attach to the different kinds of production. In the middle of the eighteenth century "subsistence," and what we should consider a very coarse and inadequate subsistence, probably seriously deficient in vitamins, appeared so much the most important economic good that the French *Économistes* insisted on calling all labor which did not get something out of the soil *stérile* or barren; and our own Adam Smith, with all his common sense, while admitting the manufacturing class into the ranks of "productive" laborers, insisted on excluding domestic servants, physicians, guardians of law and order, and all other workers who did not make up material objects, or who were not employed for profit (he never was quite sure which criterion he meant to stand by). The great Christian philosopher, Paley, believed that nothing more than a "healthy subsistence" was required for perfect happiness. Even Malthus and his immediate disciples, when they insisted on the desirability of the working-class having a high standard of comfort, seem to have done so more because this would prevent the "misery" of semi-starvation for adults and absolute starvation for infants than because there is a direct advantage in being comfortable. Ricardo said "the friends of humanity cannot but wish that in all countries the laboring classes should have a taste for comforts and enjoyments," not apparently because comforts and enjoyments are good in themselves, but because "there cannot be a better security against a superabundant population," the population being superabundant, in his opinion, when it is subject to famine.

All this emphasis on food is now out of date. We no longer look forward to a future in which an increasing population will be forced by the operation of the law of diminishing returns to devote a larger and ever larger proportion of its whole labor force to the production of food. We know that even in the past, with a rapidly increasing population, the returns to agricultural industry have increased so much that civilized mankind has been able to feed itself better and better, while giving a smaller and ever smaller proportion of its whole labor force to the production of bare subsistence; and we can reasonably expect that the increase in the productiveness of agricultural industry will be at least as great in the future, so that under the combined influence of the "narrow capacity of the individual human stomach" and the stationary number of stomachs, not only a smaller and ever smaller proportion, but a smaller and smaller absolute number of workers will be able to raise food for the whole.

Even the politicians, who for the most part follow the economists with a sixty or seventy years' lag, are beginning to realize the change, and are losing their enthusiasm for schemes for "settling more people on the land," either in colonies or at home, and thereby increasing the already excessive depreciation of agricultural compared with manufactured products. The numerous subsidies which they still give to agriculture are mostly of an eleemosynary character intended to relieve distress, and the encouragement which they give to agricultural production is only an incidental effect, unintended and often deplored. They are defended, not on the ground that they increase food, but because they are supposed to increase employment.

The necessary change of emphasis applies not only as between food and other things, but as between most primary and most finishing industries. In face of rapidly growing knowledge and slowly growing or stationary population, it is inevitable that the "staple" or "heavy" industries which provide materials should decline relatively to those which provide finished goods and services. The demand for each of such things as pig-iron and yards of cloth is easily satiated; and so also, no doubt, is the demand for cricket-bats and chauffeurs. But the minor or "lighter" industries are susceptible of an indefinite multiplication which makes the demand for their products, taken as a whole, insatiable. Increase a person's power of spending, and he will not increase his purchases in weight or bulk so much as in refinement of form, so that a richer people will devote a less proportion of their labor to producing things like pig-iron and bricks. Moreover, the mere fact of the disappearance of rapid increase of population tends to increase the proportion of demand which can be satisfied from scrap without fresh primary production. So, given a stationary population with rapidly increasing knowledge applied to production, we may expect the already observable tendency towards a less proportion of the whole labor-force being employed in the "heavy industries" and a larger in the lighter industries to become more pronounced. Perhaps we see this even now in the slight drift of industrial population from the North to the South of England which appears to be taking place.

Another change of emphasis, of little importance on the Continent, where the West-Ricardian theory of rent never took real root, but of great importance in England and other English-speaking areas, is in respect of the landowners' share of the community's income. The disappearing bugbear of diminishing returns carries away with it the vampire rural landlord, who was supposed to prosper exceedingly when diminution of returns made food scarce and dear. You all know the famous passage in which J. S. Mill described the landlords as they appeared to him and the school which he, a little belatedly, represented:

> The ordinary progress of a society which increases in wealth is at all times tending to augment the incomes of landlords; to give them both a greater amount and a greater proportion of the wealth of the community, independently of any trouble or outlay incurred by themselves. They grow richer, as it were, in their sleep, without working, risking, or economizing.[3]

Perhaps the disciple went a little beyond his master, Ricardo, in asserting so roundly that in a prosperous society the landlords must tend to get a larger and ever larger *proportion* of the whole income, but there can be no doubt that this was the impression which the Ricardian school conveyed to the public, and which formed the foundation for Henry George's scheme of land nationalization and the agitation for land-value taxation. If the school had only meant to teach that the land became more valuable absolutely—in the sense of being worth a larger absolute amount of commodities rather than a larger proportion of all the commodities and services constituting the community's income—they could not have supposed land so peculiar, since it would share this characteristic with many other things—with anything which was more limited in supply than the generality.

To grasp the completeness of the change of view which has taken place in the last hundred years, we must notice that Mill and the whole school which he represented were thinking not of the few lucky landlords who have inherited land which has been selected by nature or accident as the site of a city, but of the ordinary rural agricultural landlords. So far have we moved that the land-value taxers of to-day quite cheerfully propose to exempt all "purely agricultural value" from the imposition which they advocate.

Envy of the happy owners of such urban land as rises in value more than enough to recoup what they and their predecessors in title paid in road making, sewering and other expenses of "development" plus loss, if any, in waiting for income, still plays a part in contemporary politics, but the economist foresees that there will be at any rate less of such rise of value when the adult population ceases to increase and the demand for additional houses and gardens consequently disappears. He realizes that if any such rise continues, it will be due to the people being not only able, as they doubtless will be, to occupy a larger area with their houses and gardens, but also desirous of doing so. He will think this quite possible, but will not be confident about it, when he reflects that the vast spread of villadom may be only a temporary phenomenon, and that the married couples of the future, childless or with small families, may be more content with flats in towns and little bungalows with tiny curtilages right in the country.

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[3] "Principles," Bk. V, ch. ii, § 5.

The disappearance from economic theory of the picture of the vampire landlord taking an ever-increasing proportion of the whole produce of industry which was itself decreasing per head of workers, leaves the theoretic arena open for discussion of the sharing of the whole produce between earnings of work and income derived from possession of property of all kinds.

As to this, the economists of a hundred years ago had nothing to say. If they thought of the question at all, they mixed it up hopelessly with the rate of interest on capital, imagining property to receive a smaller proportion when the rate of interest fell, and *vice versa.* The Socialists, who followed them in fact the more closely the more they denounced them, failed completely to clear up the confusion, and it dominates the mind of the lay public even now—much, I admit, to the discredit of the economists, who should have taught that public better.

While there are no statistics on the subject worth much, and none covering any considerable area either of place or time, past history is sufficiently known to assure us that increasing civilization has, in fact, made the aggregate share of property grow faster than that of labor, the obvious cause of this being that useful things constituting property have grown faster than population, and so much faster that what decline of the rate of interest has taken place has not been sufficient to counteract the tendency. The most primitive people had scarcely any tools, and their buildings, if any, could be erected in a few hours. Ownership certainly did not then give a claim to about one third of the whole income, as statistics suggest that it does in modern western countries.

There is nothing to show that this tendency will be either reversed or intensified by a cessation of the growth of population. The cessation will, of course, tend to reduce the desirability of additional equipment; a large part of the additions of the past have been required simply to enable the additional people to be provided with tools, houses and other instruments of production or enjoyment. But additions to equipment will be made with less sacrifice of immediate enjoyable income than before, so that the increase of quantity may be sufficient to counteract the decline in the value of the units. Moreover, it is quite impossible to say what the tendency of invention may be in the future—whether to enhance or to diminish the value of additional material equipment.

But the history of the last hundred years suggests that this question of the division of income between property and labor is losing whatever importance it possessed. The economists and socialists of a hundred years ago were little removed from the time when it was common to talk of "the laboring poor," as if society was pretty sharply divided into poor workers on the one side and rich owners of property on the other. There were, indeed, some members of the propertied classes who were poor, but they were offshoots of the wealthier families rather than members of the proletariat with a little property. How innocent the mass of the people were of the crime of owning anything you may realize if you recollect that none of the agencies with which we are familiar for enabling them to invest had then got beyond the embryo stage. Friendly societies, cooperative societies, building societies, savings banks, are all modern growths. Before their advent a worker could, of course, become a small master —never, I think, a small mistress—and from a small master grow to be a big master, but if, for any reason this was not open to him, what could he do with savings, supposing he was able to make any? Put them in a stocking, or the thatch, or under the garden soil, and if they happily escaped accident there, and accumulated sufficiently, give them to an attorney of doubtful honesty to be lent out on mortgage. I remember only about fifty years ago being told by a booking-clerk at a moorland station, about a hundred miles from London, how two old women had recently paid for return tickets to London in threepenny-bits, and by a solicitor that an old man from the same district had just brought him for investment on mortgage a large sum in gold which he had so far been keeping in the thatch of his cottage. All this is now changed, and when property, as a whole, and not merely the large property-owners, is attacked, the great investing agencies of the "working classes" become formidable opponents and are supported by the small direct investors who have been helped by them.

And while many of the working-class have become property owners, many of the propertied class have become the paid servants of public companies and other institutions, so that the old sharp distinction between the wage-earner and the capitalist is become a thing of the past, and the division of income between property and labor is no longer a division between two classes composed of different individuals, but a division between two sources of income largely possessed by the same individuals.

Thus, in distribution, emphasis on the old categories of land, capital and labor is rapidly becoming obsolete and is being replaced by emphasis on individual riches and poverty, however arising. No longer do we think of relieving poverty by improving the terms of the general bargain which theory conceives labor as making with capital; we are much more likely to meet with arguments that individual poverty is being caused by this general bargain being too much in favor of the wage-earners. It is no longer the lowness of standard earnings that worries the philanthropic economist, but the fact that so many people are unable to rank themselves among recipients of those wages. Emphasis is on unemployment.

Unemployment is not really a very modern phenomenon. The crowds of beggars who collected their daily dole in the Middle Ages from the monasteries and from private wayfarers and householders were, perhaps, as large a proportion of the population as the normal registered unemployed of to-day. The "distresses" of the period just preceding a hundred years ago seem to have been accompanied by enormous unemployment, but we have no reliable statistics, and the loose statements, such as that in Birmingham in 1817 one third of the workpeople were wholly unemployed and all the rest on half-time, do not help us much. But so far as I know, it has never been contended that history shows unemployment to be greater when population (or even population of working age) is rapidly increasing.

Yet it is common to talk of "the difficulty of providing employment for a rapidly increasing population," and some eminent authorities quite recently endeavored to console the public by alleging that the coming decline in the growth of numbers will greatly alleviate the present situation in regard to unemployment.

I believe this to be a profound error, based on an elementary misconception of the origin of demand. The old proverb, "With every mouth God sends a pair of hands," is true and valuable, but no more so than its converse, "With every pair of hands God sends a mouth." The demand for the products of industry is not something outside and independent of the amount of products. The demand for each product depends on the supply of products offered in exchange for it, and the demand for all products depends on the supply of all products. Consequently, there is not the slightest danger of the working population ever becoming too great for the demand for its products taken as a whole.

Unemployment arises not from insufficient demand for the products of industry as a whole, but from the number of persons offering to work in particular branches of industry being in excess of the number admissible, having regard to the conditions and wages which are required to satisfy both the would-be workers who are unemployed and the persons already in employment. If the unemployed will not take what employers would offer them, the case is simple, and it is only a little more complicated if they are willing to take, and the employers are willing to give, something less than what is paid to the persons already employed; but the two parties are prevented from coming to terms on that basis by the fact that those already employed would go out on strike if the additional contingent was accepted at a lower rate than that which they themselves are receiving.

Now one of the commonest causes of such a situation is a falling off of demand for the products of a particular branch of industry. The fact that the demand for any product, let us say coal, for example, falls off, is a good reason for fewer persons being employed in that branch of industry and more in other branches. If the diminution of demand is very gradual, the necessary reduction in personnel can be effected by a cessation of recruiting. Many a branch of industry has gradually wilted away in this manner without much inconvenience or hardship to any one. But if the diminution is more sudden, unemployment results owing to the natural reluctance of persons skilled, or at any rate experienced, in the particular branch of industry to leave it and try for employment in some other. The thoughtless outsider is apt to say that both the unemployed and those who are still employed in the branch should accept lower wages, and so by cheapening the product, extend the demand for it. As a temporary palliative this may sometimes be reasonable, but it is evidently never the best final solution of the difficulty. It is not reasonable that a trade should be continuously worse paid than others merely because the demand for its products was once bigger than it has become. What the diminution of demand calls for is a redistribution of labor force, fewer persons being allotted to the branch of industry of which the products are less in demand, and more persons to the other branches.

But when population is increasing, absolute diminutions of demand are likely to be somewhat fewer, and somewhat less acute when they do occur, than when population is stationary. If, for example by the introduction of oil, or more economical consumption, the average person's demand for coal is reduced by one tenth, in a stationary population the total demand for coal would be reduced by one tenth; but if the population in the same time increased 12 per cent., the total demand would be not reduced but slightly increased, and there would be no employment difficulty.

We ought therefore not to imagine that a stationary or declining population will rid us of the trouble of unemployment. It will provide more rather than less reason for promoting mobility of labor in place and occupation, and we shall have to take more care, rather than less, than at present to secure that arrangements, which seem superficially desirable, do not hinder that mobility.

It is inevitable, I suppose, that the question will be asked, whether cessation of the growth of population is to be regarded as a good or an evil turn in human history. But the limitations of economics and perhaps of human nature prevent any straight answer being given. Nationalists in each nation want their own nation to increase in comparison with others; if they think of the others' interest at all, they say and believe that it will be promoted by the predominance of their own nation. We can get no further that way, since the pretension of each is contradicted by the pretensions of the others. If we try to avoid this obstacle by saying that we will ignore national and racial differences, and assume either that somehow the generally fittest will grow at the expense of the others, or that each as well as the whole will have stationary numbers, we still have to face the fact that our conception of the distinction between economic welfare and welfare of other kinds is nebulous in the extreme, and that if it was clearer, we should not know—I think we never can know—how much of the one should be regarded as equal to a given quantity of the other.

Different persons will give different answers. Some agree with Paley that ten persons with sufficient subsistence must be in possession of more welfare than a single millionaire; others with J. S. Mill that the world turned into a "human anthill' would be an undesirable place of residence. The same person will give different answers according to his mood at the moment. Personally, I spent my early boyhood in a town which throughout my life has been the most prosperous in England, and I have long lived in another which, having added motor manufacture to education in its old age, has lately been growing nearly as fast, and sometimes when I contemplate their growth I feel a little like G. R. Porter when he wrote the "Progress of the Nation," during the period 1800 to 1831. At other times, and I think more often, I regret the open heath and the untouched pine wood which stretched in my early recollection to within a few hundred yards of the Bath Hotel at Bournemouth, and I hate the gasworks straddling the river and the bungalows shutting in the main roads out of Oxford; then I agree with Mill that it is well that population should become stationary long before necessity compels it.

After all, the increase must stop some time, and watching the effect of the stoppage will be a very interesting experience which I should like to have been born late enough to enjoy.

THREE HUNDRED YEARS OF TOM THUMB

By Dr. **HARRY B. WEISS**
NEW BRUNSWICK, N. J.

AT the outset, I may as well admit that I have no intention, in this account, of tracking the story of Tom Thumb to its lair. Although this has been attempted by various learned men, the results are not always satisfying. Dr. Johnson, it is said, once "withdrew his attention" from a great man who bored him and "thought about Tom Thumb." Without seeming to place myself in such distinguished company, perhaps I too may be permitted to say that my thoughts about Tom Thumb are the result of boredom, or if you prefer, idle curiosity.

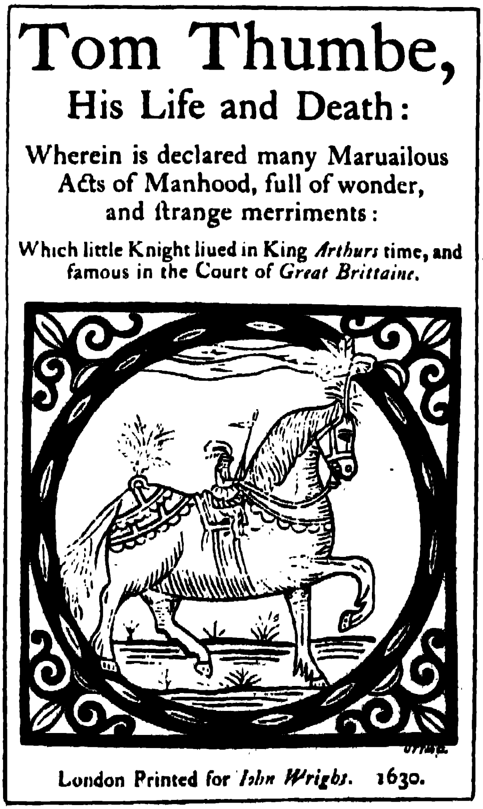
Although I am concerned here mainly with the changes which have taken place in the version during the past three hundred years, it seems necessary to mention briefly a few facts and dates relating to early information about Tom Thumb. Reginald Scot, in his "Discoverie of Witchcraft," printed in 1584, speaking "Of vaine apparitions, how people have beene brought to feare bugges," mentions "Tom thombe" along with the giants, imps, fairies, satyrs, witches, goblins, etc., with which "in our childhood our mothers maids have so terrified us." And Thomas Nashe in "Pierce Penilesse His Supplication to the Diuell" (1592) grumbles that "eury grosse braind Idiot is suffered to come into print, who if hee set foorth a Pamphlet of the praise of Pudding-pricks, or write a Treatise of Tom Thumme, or the exploits of Vntruss; it is bought vp thicke and threefold, when better things lie dead."

In 1621 the tale appeared, in prose, in Richard Johnson's "The History of Tom Thumbe the Little, for his small stature surnamed King Arthur's Dwarfe: Whose Life and aduentures containe many strange and wonderfull accidents, published for the delight of merry Time-spenders." Tom Thumb also appears in Drayton's "Nymphidia" (1627) and it would be possible to mention other notable instances where Tom Thumb has been utilized to advantage, such as Fielding's burlesque, "Tom Thumb A Tragedy" (1730) and Kane O'Hara's "Tom Thumb; A Burletta, Altered from Henry Fielding" (1830).

The earliest Tom Thumb in Europe appears to be the Thaumlin or Little Thumb of the Northmen, a dwarf of Scandinavian descent. The popular Danish history of Svend Tomling treats of "a man no bigger than a thumb, who would be married to a woman three ells and three quarters long." Then there is the "Daumerling," a little Thumb of the Germans, who is swallowed by a dun cow. It is said that the German and Danish "Thumb" stories contain much that is found in the northern versions. In India Tom Thumb has his counterpart in the Khodra Khan of the Mohammedans. In the Hindoo story, Vamuna is so tiny that he thinks the water-filled impression of a cow's hoof in the earth is a lake and he begs King Mahabali for a piece of ground over which he may walk in three strides.

Tom Thumb, a comic story, belongs to one of the groups or divisions of the so-called Swallow cycle. The hero is swallowed by a cow, a giant, a fish, a miller and a salmon, and escapes from all in safety. According to Macculloch, many swallow myths gradually change into stories which attempt to account for various natural events. The curiosity of man makes him invent stories explaining such events. Or an inventive story-teller might build upon an old myth. Many folk-tales of various countries have been changed and modified during the passage of centuries, yet they retain some common characteristics and enough of their antiquity to identify them as the remains of beliefs, customs and ideas of a forgotten age.

In this account, however, we shall not go back beyond the 1630 edition of Tom Thumb, which was bequeathed to the Bodleian Library by the author of the "Anatomy of Melancholy." This small black letter edition bears the title "Tom Thumbe, his life and death: wherein is declared many maruailous acts of manhood, full of wonder, and strange merriments. Which little knight lived in King Arthurs time, and famous in the court of Great Brittaine. London, printed for John Wright. 1630." The ballad, consisting of 135 lines, opens as follows:



Tom Thumbe,
His Life and Death:
Wherein is declared many Maruailous
Acts of Manhood, full of wonder,
and ſtrange merriments:
Which little Knight liued in King *Arthurs* time, and
famous in the Court of *Great Brittaine*.

London Printed for *Iohn Wright*. 1630.

FIG. 1. TITLE PAGE OF THE 1630 EDITION OF "TOM THUMBE" SHOWING TOM ON KING ARTHUR'S HORSE.

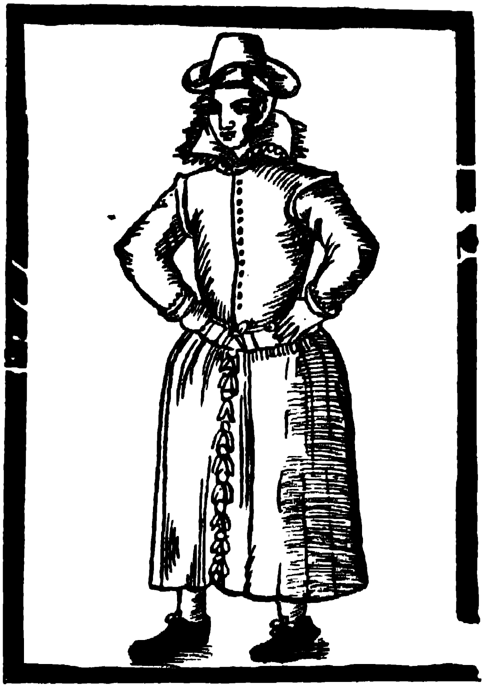


FIG. 2. TOM THUMB'S MOTHER (1630 EDITION).

In Arthurs court Tom Thumbe did Liue,
  A man of mickle might,
The best of all the table round,
  And eke a doughty knight:

His stature but an inch in height,
  Or quarter of a span;
Then thinke you not this little knight,
  Was prou'd a valiant man?

His father was a plow-man plaine,
  His mother milkt the cow,
But yet the way to get a sonne
  "This" couple know not how,

Until such time this good old man
  To learned Merlin goes,
And there to him his deepe desires
  In secret manner showes,

How in his heart he wisht to have
  A childe in time to come,

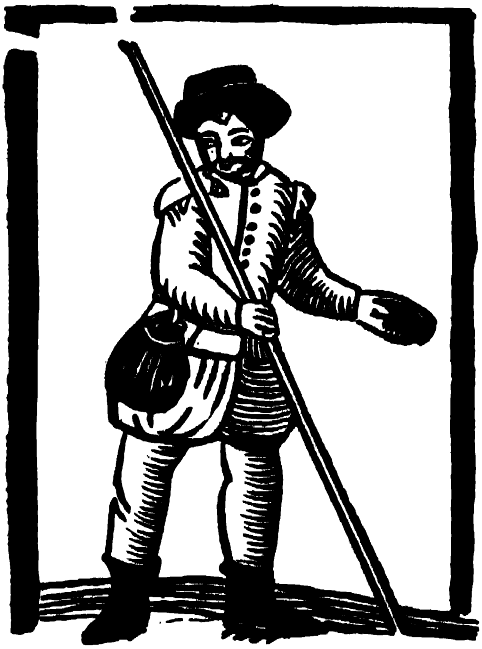


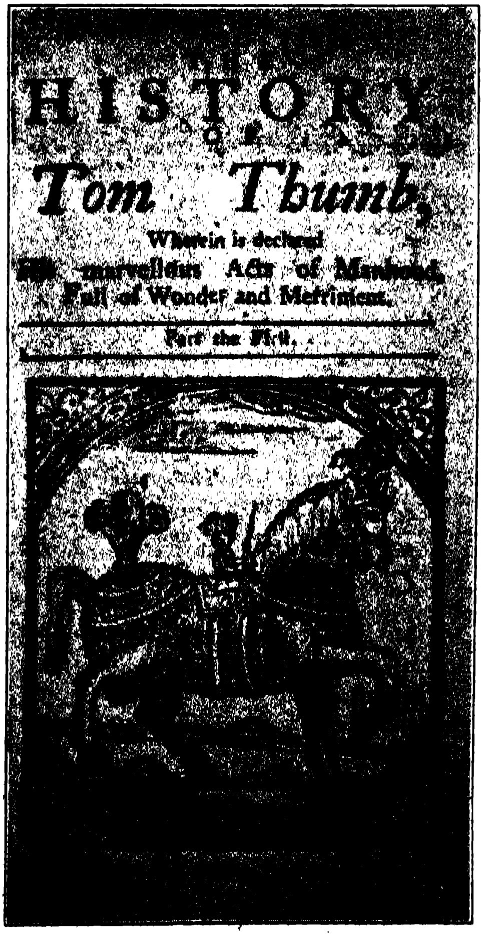
FIG. 3. TOM THUMB'S FATHER (1630 EDITION).

To be his heire, though it might be
No bigger than his Thumbe.

Merlin told the plowman that his wish would come true and Tom was eventually "begot and borne in halfe an houre" and in four minutes he grew as tall as the plowman's thumb. Of course he was under the protection of the fairies, and at his christening, which was attended by the "Fayry-Queene" with her "traine of Goblins grim," he was named Tom Thumb. Little is told of his early childhood. The fairy queen clothed him in garments which lasted many years, a hat made of an oak leaf, a shirt of a spider's web, his hose and doublet of thistle down, his garters, two little hairs pulled from "his mothers eye" and his boots and shoes from a mouse's skin. Thus attired he sallies forth to play with the neighboring children, losing his "cherry stones," stealing a fresh supply from his playmates, indulging in such tricks as hanging "Black pots, and glasses vpon a bright sunnebeame," and laughing at the whippings which the other boys received when their attempts to do the same ended in broken crockery. Because of the turmoil which Tom created when he went out to play, his mother kept him at home, and from then on his adventures commenced in earnest.

He sate vpon the pudding-boule,
The candle for to hold;
Of which there is vnto this day
A pretty pastime told:

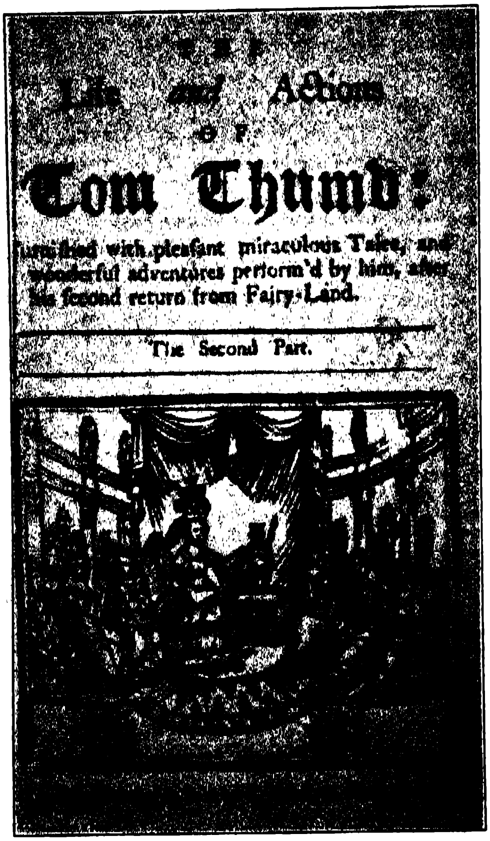
For Tom fell in, and could not be
For euer after found,



HISTORY
OF
Tom Thumb,
Wherein is declared
[illegible] marvellous Acts of Manhood,
Full of Wonder and Merriment.

Part the First.

FIG. 4. TITLE PAGE OF A PETTICOAT LANE EDITION OF TOM THUMB.



THE
Life and Actions
OF
Tom Thumb:
furnished with pleasant miraculous Tales, and wonderful adventures perform'd by him, after his second return from Fairy-Land.

The Second Part.

FIG. 5. TITLE PAGE OF THE SECOND PART OF THE PETTICOAT LANE EDITION.

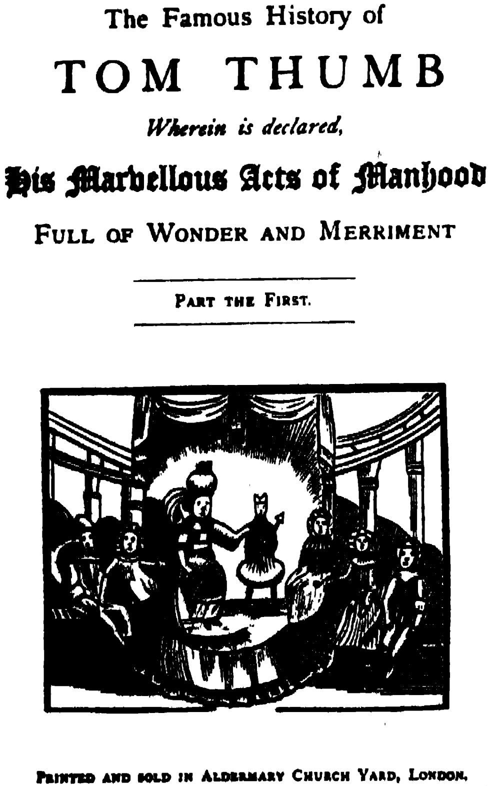
For in the blood and batter he
  Was strangely lost and drownd.

Although his mother searched long, it was in vain, and unknowingly she thrust her son into the pudding and the pudding into the kettle. But the pudding bounced around so violently that she thought the devil was inside and very charitably she bestowed it upon a passing tinker. Tom's voice issuing from the pudding scared the tinker so that he threw it down and ran. Tom then emerged and returned home, but only to get into fresh trouble. When Tom's mother went to milk her cows, she tied him fast to a thistle so that the blustery wind would not blow him away, but alas, a cow came by and ate the thistle, Tom and all, and Tom traveled the entire length of the cow's alimentary canal. His next escapade happened while he was helping his father plow. He fell into the furrow, was carried away, just like a grain of corn, by a raven and

Unto a giants castle top,
  In which he let him fall,
Where soone the giant swallowed vp
  His body, cloathes and all.

But in his belly did Tom Thumbe
  So great a rumbling make,
That neither day nor night he could
  The smallest quiet take,

Until the gyant had him spewd
  Three miles into the sea,
Whereas a fish soone tooke him vp
  And bore him thence away.



The Famous History of
TOM THUMB
Wherein is declared,
His Marvellous Acts of Manhood
FULL OF WONDER AND MERRIMENT

PART THE FIRST.

PRINTED AND SOLD IN ALDERMARY CHURCH YARD, LONDON.

FIG. 6. TITLE PAGE OF AN ALDERMARY CHURCH YARD EDITION OF TOM THUMB.

The fish was caught and sent to King Arthur. Tom was discovered and enjoyed high favor at court. He danced a "galliard braue vpon his queenes left hand," went on hunting trips with the king, paid a visit to his parents, who feasted him three days on a hazel nut, and returned to King Arthur's court where he engaged in tournaments, vanquishing all his opponents to the great amazement of the knights, but as a result of such strenuous exertions finally becoming sick, and dying, in spite of the skill and cunning of King Arthur's physician.

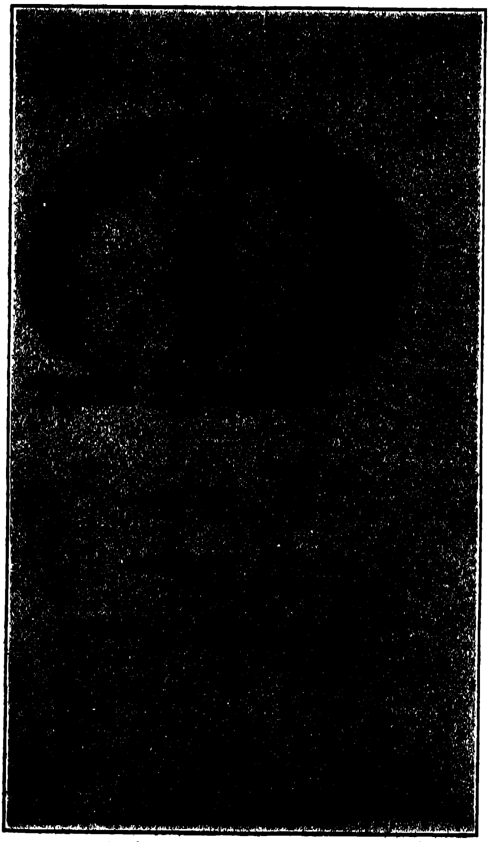


FIG. 7. A BANBURY EDITION OF TOM THUMB.

And so with peace and quietnesse
He left this earth below;
And vp into the Fayry Land
His ghost did fading goe.

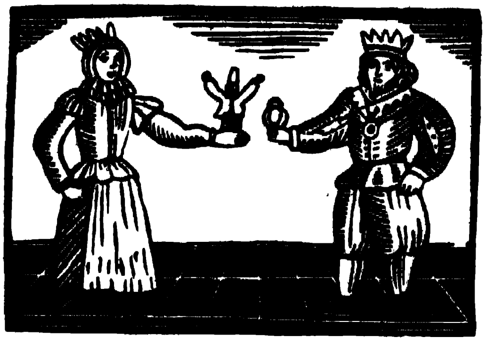


FIG. 8. TOM DANCING A GALLIARD UPON THE QUEEN'S LEFT HAND (ALDERMARY CHURCH YARD ED.)

He was received by the Fairy Queen "with musicke and sweet melody" and King Arthur, after mourning with his knights for forty days, built a "tomb of marble gray," "in remembrance of his name."

Thus ends what appears to be the original tale of Tom Thumb, but the story was amplified by the addition of a second and third part, both detailing fresh adventures but lacking the charm and quaintness of the original version. Hazlitt has stated that the author of these later parts was "not trammelled by rhythm, grammar or geography." The second part commences with Tom's return from fairyland and his fall

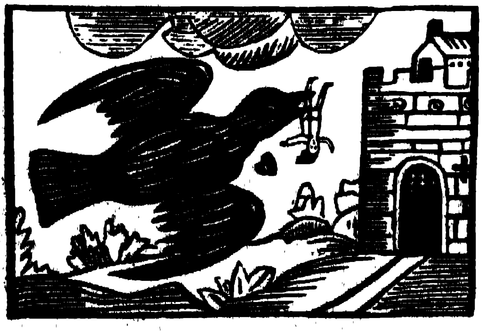


FIG. 9. "NOW BY A RAVEN OF GREAT STRENGTH AWAY POOR TOM WAS BORNE."
(ALD. CH. YD. ED.)

"into a pan of firmity," in good King Edgar's court, causing the cook to drop the pan and mess things up generally. Tom was dragged over to the king's table, where

> With clubs and staves, forks and prongs,
> He guarded was, unpitied,
> To answer for the mighty Wrongs,
> Which he had there committed.

Just as they began to vote on what form his death should take, Tom escaped from such an unfriendly atmosphere by jumping down a miller's throat and in addition to whistling, singing and dancing,

> Tom often pinch'd him by the tripes,
> And made the Miller roar,
> Alas! alas! ten thousand stripes
> Could not have vex'd him more.

After calling in the doctor and twenty learned men and after confessing to various thefts, the miller jumped in a river "and turn'd Tom Thumb into the tide," where he was swallowed by a salmon which was caught and finally purchased by the king's steward. Tom was brought before the king, impaled on a fork, but the affairs of state were not to be interrupted then by such a slender cause and so the cook was instructed to keep Tom a prisoner, which he did by binding him hand and foot and placing him in a mouse trap. After an interval of a week, Tom was taken before the king, but he made such a good plea that he was pardoned and taken into favor.

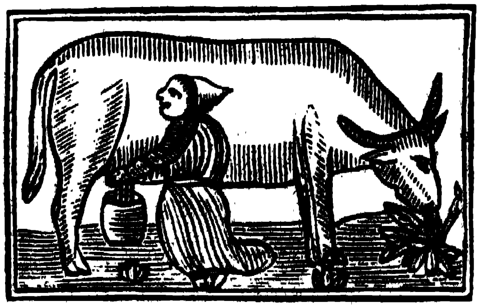


FIG. 10. THE THISTLE-EATING COW WHICH SWALLOWED TOM.

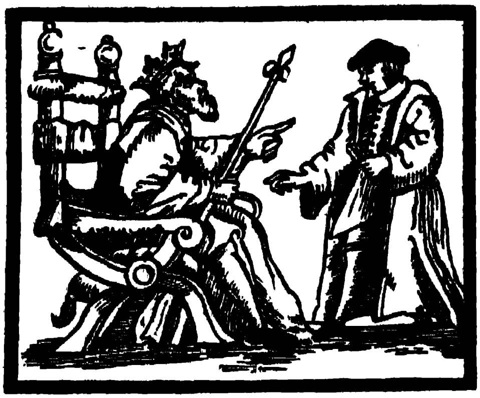


FIG. 11. KING ARTHUR RECEIVING A REPORT, ABOUT TOM, FROM THE DOCTOR (1630 ED.).

His troubles, however, were not at an end. While riding on a mouse, a-hunting with the king, a farmer's cat captured both and ran to the top of a tree. After a sad and bloody fight during which the cat scratched and Tom ran his sword through her, the cat dropped him. From this encounter he did not recover. His injuries were too severe. And so the fairy queen sent "a mighty swarm of pretty Fairy Sprites" for him.

> They put him in a winding sheet,
> More white than Lillies fair,
> These Fairies all with music sweet
> Did mount the lofty air.

But "death's fatal arrows prov'd in vain," because "he was hurried back again down from the Fairy Land," and a third part of the tale deals with "his Marvellous Acts of Manhood, performed after his second return from Fairy Land." His first adventure, however, after reaching the earth was so undignified and so devoid of romanticism that only in a "limited and unexpurgated" edition would it be proper to mention it. In due course Tom finally appeared before King Thunston's court where he underwent another trial, coming through, as usual, with honors and ingratiating himself with the king. In

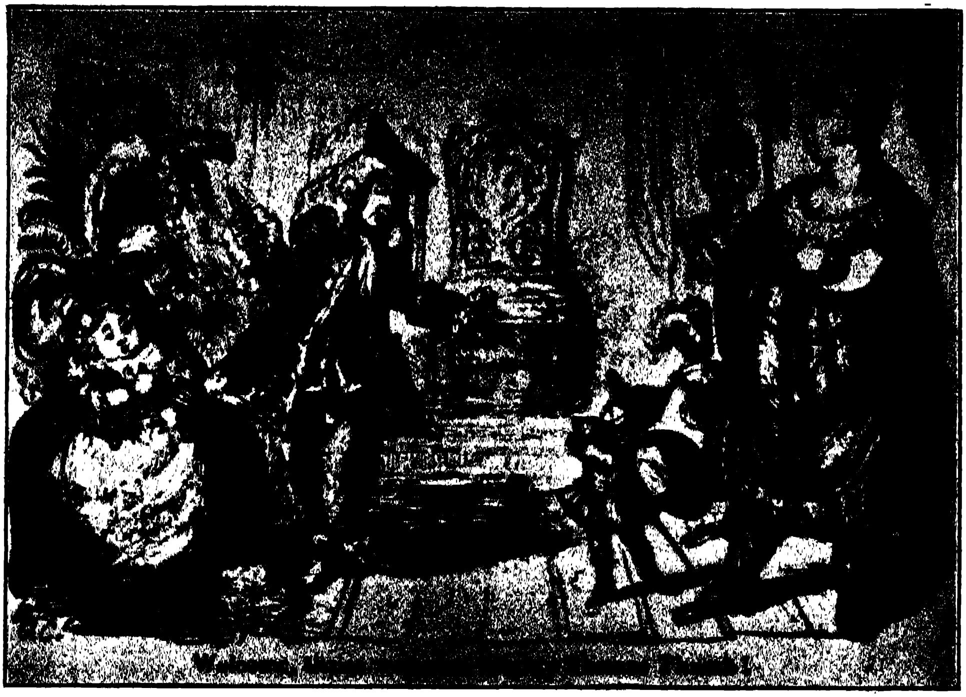


FIG. 12. FRONTISPIECE TO KANE O'HARA'S BURLETTA "TOM THUMB" SHOWING GEORGE CRUIKSHANK'S CONCEPTION OF TOM. (1830).

fact the king thought so highly of Tom that he bought him a coach drawn by six mice and he lived in splendid ease. But horrors! the microscopic wretch attempted to ravish the queen and,

The Queen, with rage and fury fir'd,
  To see herself abus'd,
That of the King she then desir'd,
  Tom Thumb might be accus'd.

That nothing would her wrath appease,
  To free her from all strife,
Or set her mind at perfect ease,
  Until she had his life.

Tom escaped this time on a butterfly which after giving him an uncomfortable ride, unluckily flew back to the court where Tom was discovered and captured. He was brought to trial, a very sick man, and

So the King his sentence he declar'd,
  How hanged he should be,
And that a Gibbet should be rear'd,
  And none should set him free.

Tom was imprisoned in a mousetrap, but a cat, mistaking him for a mouse, broke his prison and in endeavoring to escape he fell into a spider's web.

The spider, watching for his Prey,
  Tom took to be a fly,
And seized him without delay,
  Regarding not his cry.

The blood out of his body drains,
  He yielded up his breath;
Thus he was freed from all Pains
  By his unlook'd for death.

Thus you have heard his actions all,
  Likewise his actions great,
His Rise, his Progress, and his fall,
  Thus ushered in by fate.

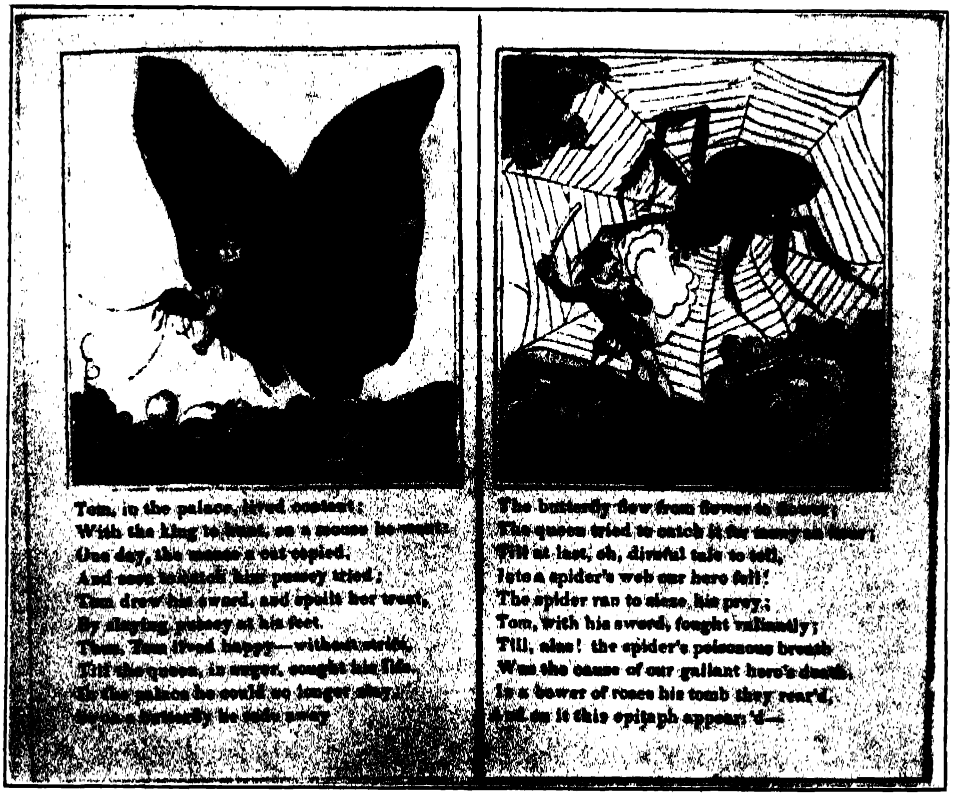
Although he's dead, his Memory lives,
  Recorded ever sure;
His very name some pleasure gives,
  And ever will endure.

This in brief is the story of Tom Thumb as told in three parts. During the reigns of James I, Charles I and

Charles II, Tom Thumb enjoyed continued popularity, and he was frequently mentioned by contemporary authors. Ritson in 1791, when he reprinted the 1630 version of Tom Thumb in his "Pieces of Ancient Popular Poetry" (London), said that "every city, town, village, shop, stall, man, woman and child in the kingdom" was familiar with it. John Newbery published editions in 1768, 1786 and 1789. Various versions circulated as chapbooks down to the beginning of the nineteenth century and even later. The tale was popular in this country, too. In the Boston, Massachusetts, *Chronicle* for August 29, 1768, John Mein advertised "The Famous Tommy Thumb's Little Story Book: Containing His Life and Surprising Adventures," etc. "London: Printed for S. Crowder." And in 1686, or some 80 years earlier, John Dunton sold "The History of Tom Thumb" in his Boston warehouse. Although these titles were imported, the tale was printed in this country. John Boyle, of Boston, in 1771 printed "The Famous Tommy Thumb's Little Story-Book. Containing his Life and Adventures." And later, in 1813, N. Coverly, Jr., Milk Street, Boston, printed "The Life and Death of Tom Thumb." However, English editions with their quaint woodcut illustrations continued to circulate in this country until the middle of the nineteenth century, some gaily colored in red, pink and green. Mc-

FIG. 13. TITLE PAGE OF PARK'S "TOM THUMB."

FIG. 14. TITLE PAGE OF McLOUGHLIN BROTHERS' TOM THUMB (1870 OR 1871).



Tom, in the palace, lived content;
With the King to hunt, as a mouse he went:
One day, the queen a cat espied,
And soon to catch him pussey tried;
Tom drew his sword, and spoilt her treat,
By slaying pussey at his feet.
Then, Tom lived happy—without strife,
Till the queen, in anger, sought his life.
In the palace he could no longer stay;
[illegible] a butterfly he rode away.

The butterfly flew from flower to flower;
The queen tried to catch it for many an hour,
Till at last, oh, direful tale to tell,
Into a spider's web our hero fell!
The spider ran to seize his prey;
Tom, with his sword, fought valiantly;
Till, alas! the spider's poisonous breath
Was the cause of our gallant hero's death.
In a bower of roses his tomb they rear'd,
And on it this epitaph appear'd:—

FIG. 15. TWO PAGES FROM PARK'S HISTORY OF TOM THUMB. (184–).

Loughlin Brothers in 1870 or 1871 published "Tom Thumb" in their "Cinderella Series" and at present various American publishers of children's books usually include a stray title of "Tom Thumb" in their lists. But all in all, Tom is not nearly so popular now as he was fifty or seventy-five years ago.

Ever since the story has been current, Tom's thrilling adventures have been told and retold, with modifications by each generation, and many variations occur in the numerous editions within a generation. Although the coarseness of the seventeenth century would not be permitted to circulate in the nurseries of to-day, it should be remembered that in the seventeenth century Tom Thumb was as popular with adults as with children, and no doubt some of the allusions in the early accounts were not intended particularly for childish understanding.

Some of the liberties taken with the text appear to be quite unnecessary. In present-day versions, no one will object to the deletion of expressions which are now highly unconventional and which are objectionable to those of squeamish sensibilities—at least not so long as the early versions are obtainable. However, nearly every one who has arranged the tale for publication has made changes, probably under the delusion that the original was being improved upon. And so in some present-day accounts we are told that Merlin, because the plowman's wife refused him admittance to her home, when he was cold, revenged himself by seeing to it that her baby boy grew no bigger than her thumb. The thistle which the cow ate in 1630 has now become a buttercup. Tom's hat is made, not of an oak leaf but of a rose leaf. And under no circumstances is Tom now allowed to get beyond the cow's mouth. His mother either saves him in time or the cow sneezes him to safety or the cow, hearing strange noises in her throat, simply opens her mouth without further ado and Tom falls out.

The real reason for the queen's displeasure with Tom is never even hinted at. That of course would be unthinkable, and so the queen is made to appear jealous because Tom gets a coach and six mice, or no reason is given at all. Kisses have been injected into modern versions also. Tom's mother kisses him after he escapes from the pudding and before she puts him to bed. Such an act of endearment seems strangely out of place in Tom Thumb's life. He is not at all kissable, and his adventures are not of the sort that admit expressions of affection. But when "adapters" and "arrangers" go so far as to have Tom place carpet tacks in the path of the cat—then something should be done about it.

Many years ago, Dr. Wagstaffe concluded that although Tom Thumb was looked upon merely as entertainment for children, it was "perhaps a performance not unworthy the perusal of the judicious." Dr. Wagstaffe believed that the design of the tale was to recommend virtue and to demonstrate that "however any one may labour under the disadvantages of stature and deformity, or the meanness of parentage, yet if his mind and actions are above the ordinary level, those very disadvantages that seem to depress him add a lustre to his character." Even now some of our "adapters" show a trace of Hannah More-ism at the ends of their adaptations, but for the most part Tom Thumb has been fortunate in escaping the clutches of the moralists.

According to tradition, Tom Thumb died at Lincoln, which was one of the five Danish towns of England, and according to the same tradition his tombstone was a little blue flagstone, in the cathedral, which has long since disappeared. Although the authenticity of this remains uncertain, there can be no doubt about Tom Thumb himself being very much alive to-day, which is my excuse for bringing him up, as Thomas Nashe has said, "thicke and threefold, when better things lie dead."

SCIENCE SERVICE RADIO TALKS

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HEREDITY AND DISEASE

By Dr. **CHARLES B. DAVENPORT**

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SOME years ago, in speaking with a medical man about the possible hereditary factor in tuberculosis, he showed astonishment that I should suggest there might be such a factor. He stated that it is now well known that the *Bacillus tuberculosis* is the sole cause of tuberculosis in man. The obvious response was to call his attention to the fact that the *Bacillus tuberculosis* can be inoculated into a horse or goat without producing symptoms of tuberculosis and, while practically every adult person carries *Bacillus tuberculosis* in his body, only a small fraction of persons have what the medical men would call tuberculosis. The symptoms that we call tuberculosis are the reaction of particularly susceptible individuals, belonging to hereditarily non-resistant strains, to the presence and growth in their bodies of *Bacillus tuberculosis*. The constitutional, hereditary, genetical factor is as important in producing the disease as the parasitic bacillus.

Formerly we heard much of the diathesis, or constitution, that is favorable to the development of a particular disease. With the demonstration of the importance of the germ theory of disease many medical men have forgotten the importance of constitution. To-day, the pendulum is swinging back, largely on account of modern genetical studies. First of all, it has been clearly shown by Alexander Graham Bell and others that there is inheritance of longevity. If both your parents have lived to be over 80 years of age you will probably live to be over 53; while if both parents died under 60 years the average age of the children is only 33. Now in a world full of hazards of infections, longevity can only mean great bodily resistance to germs that incite diseases.

Heredity is exceedingly important in the resistance of plants to disease, as has been shown experimentally. Thus, some years ago the sugar industry was menaced by the mosaic disease, which in some years wiped out whole plantations of sugar cane. An East Indian Java cane has proved to be highly resistant to this disease and has saved the industry. The germs of mosaic have not been eliminated, but genetic immunity has been bred into the sugar cane. Many similar cases are known to plant breeders.

Similarly, experimentalists have found in different families of guinea-pigs a marked difference in resistance to tuberculosis. In humans a high correlation in the incidence of tuberculosis has been found between parents and offspring, but only a slight one between husband and wife, who are not blood relatives.

Cancer is a very wide-spread disease. Yet not every one can die of cancer. This has been shown experimentally in breeding mice. Some of the cancer tissue from a dying mouse inoculated into her sisters may cause them all to die of cancer, but similar cancer tissue inoculated into another family of mice will be destroyed in their bodies and cause no tumor at all.

Still another disease that illustrates the relation of constitution to symptoms is goiter. This is commonly thought to be due to insufficiency of iodine in the water or food. There are regions where the enlarged thyroid gland is very common, or endemic, not only among people but among dogs and other domestic animals. However, even in such regions only a fraction of the population is affected; but in certain families 100 per cent. are. There are family differences in immunity.

But how then do we account for the fact that endemic goiter occurs only where there is little iodine in the water? The explanation seems to be this. Humans differ in the effectiveness of the thyroid gland, and the degree of effectiveness is hereditary. Supposing the population placed like the successive strata of a cliff, with the least resistant at the bottom and the most resistant at the top. Let us imagine a tide of noxious environment (especially absence of iodine) to be rising with increasing noxiousness up this cliff. A low wave of noxiousness will affect only those with imperfectly functioning thyroid glands, and, therefore, only a small part of the population will be affected, but if the tide of increasing noxiousness rises it will involve a larger proportion of the population, taking in even those with fairly effective thyroid glands.

Note the delicate relation between constitution and environment upon which the disease, goiter, depends. The pathological result depends upon a disharmonious relation between heredity and environment—a thyroid too insufficient to function with the insufficient iodine intake. For a constitutionally effective thyroid a small iodine intake would suffice. Even a poorly efficient thyroid might get along without enlarging were there much iodine in the water.

This example of goiter shows clearly the relation between constitution and medication. Goiter results from a disharmony. Goiter is frequently successfully treated by iodized salt. Disharmony may be corrected by artificial means—by medicine. This principle would seem to be of general application. The girl who is going into a decline with tuberculosis may be saved by open air, good food, cod-liver oil and other care. For many, the excellent conditions in a sanitarium obliterate the disharmony between poor constitution and medium environment. If, however, the constitution is inherently very unresistant, even the excellent environment may fail. On the other hand, many highly resistant families can live under the hard conditions imposed by crowding, poor air and insufficient food without showing tuberculosis. In general, persons with strong constitution can withstand sub-optimal conditions, but where the constitution is weak the conditions of life must be the best possible.

These considerations should bring hope to the constitutionally weak and point a moral to those who wish their children to be constitutionally strong, resistant, effective in a world where the conditions can not always be the best. The hope lies in this, that if a person with a constitutional weakness early learns of that weakness and persistently keeps himself in an optimal environment he may live long. It is a function of sanitation to provide this optimal environment. It is the function of medicine to restore the harmonious balance between constitution and environment, once it is threatened. Often in the absence of knowledge concerning the constitution of the individual the medical profession advises a blanket protection. Thus we give smallpox vaccine to all. In the army all received typhoid anti-toxin. We make no allowance for natural resistance or immunity because it is impracticable to determine it.

Finally, where in the scheme of health does heredity come in? Constitution is the great fact that we must recognize. Most of us have a constitution that is sufficient for most purposes and which will last for seven or more decades. For those with some constitutional limitation it is necessary to know, first, what that limitation is and to adapt one's life—including one's biochemical life—to it. Every parent should know these constitutional limitatians of his children; how to protect the child from disharmony between constitution and environment and how to restore any threatened disharmony. A knowledge of heredity of the patient is necessary to the best results by the physician. A knowledge of one's own heredity is necessary for the more effective conduct of life. Know thyself; especially know thy constitution and its limitations!

And how shall we know our constitution? The first step is obviously to know our families and to learn how the constitutional factors have revealed themselves in our nearest kin. The study of the family history may reveal great causes of satisfaction. In my immediate family I find no insanity, no hemophilia or bleeding, no case of brittle bone. Indeed there are 100 or more diseases or defects that I have never heard of in my family. Glory be! But there is tuberculosis, arteriosclerosis. Very well. I must take particular pains to avoid the environment that permits these diseases to thrive. In general, I would urge that as much individual attention be given to the consideration of one's constitution—one's heredity—as to the treatment of disease.

Finally in marriage-mating careful consideration should be given to constitution. Of course one will hardly marry a physical or mental wreck, but one should go farther than that. It is undesirable for the deaf to marry the deaf; for two myopics or two over-active persons to marry each other. If you have any constitutional limitation select a mate from a family that does not show the same leading limitation and so shall the children receive a stronger heritage. There is a limitation to the aid that medicine can afford the weak constitution. The need is indeed greater now than ever, in these days of small families, of considering while selecting a mate the probable consequences to the children. This is the reason for eugenics.

IDENTICAL TWINS

By Professor H. H. NEWMAN

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IDENTICAL twins are those twins that look so much alike that they are often mistaken for each other. When they are babies one sometimes gets two baths and the other none, and when they are grown up even their best friends call one by the name of the other. About one fourth of all twins are identical twins, and since about one birth out of every 88 is a twin birth, one birth in every 352 is an identical twin birth.

Identical twins are of peculiar scientific interest, for they are the product of the symmetrical division of a single embryo, derived from a single fertilized egg. Such a fertilized egg typically develops into a single individual with a body composed of two nearly symmetrical halves. One half is not strictly the duplicate of the other but the reversed, or mirror-image duplicate of it. Thus your two hands are not really duplicates, but your right hand is like the image of your left seen in a mirror. Now a pair of identical twins starts out to become an ordinary single individual, with right and left symmetrical halves, but some delay or some hitch in the developmental process causes the right and left half embryos to separate, and each half to grow into a whole individual. Frequently the derivation of the twins from right and left halves of the embryo body is reflected in the fact that one of the twins is a right-hander, the other a left-hander; one of them has the whorl in the crown of the hair twisted to the left, the other to the right.

An interesting study has been made of the degree of resemblance existing between identical twins. They are always both of the same sex in a pair, and therefore identical in this respect. They have the same or nearly the same eye color, hair color, skin color; nearly the same irregularities in their teeth, nearly the same finger-prints, nearly the same shapes of ears, nearly the same features, body build, etc. In other words, they are almost complete duplicates in all their hereditary characteristics. But why are they not exact duplicates? For the same reason that the two sides of the body of a single individual are never exactly alike. Compare your two hands, your two feet, your two ears, your teeth on the opposite sides of your dental arches. They nearly always show minor differences.

Now it is very significant that when accurate measurements are made first between equivalent parts of the two sides of single individuals and then of the characters of pairs of twins, the two sides of the body are about 90 per cent. identical, and so are identical twins. Identical twins then are not strictly identical but only just as identical as the two sides of single individuals.

The two sides of the body of a person are, of course, identical in their heredity. No one doubts that for a minute, but perhaps you have not made the next inevitable step in reasoning from the facts. This next step is that the two individuals of a pair of identical twins have identical heredities. Each has inherited exactly the same combination of maternal and paternal characters from the two parents.

It is this fact that makes identical twins so important for scientific work, and for the following reason: There is an old problem that badly needs solution, namely, which is more important in the development of an individual, differences in heredity or differences in the environment—the old problem of nature or nurture. When the heredity of every individual is different and the environment also differs, how can we determine which of these differences have been more effective? It can't be done. But if we could find two individuals with exactly the same heredity and rear them under different environments we could conclude that the extent to which they remain similar is a measure of their heredity and the extent to which they become different under different environments is a measure of the effectiveness of the environment in producing differences.

It is just in this connection that identical twins come to our aid, for they represent for each pair two individuals with identical heredity. If we could separate pairs of identical twins in infancy and rear one in poverty and the other in wealth, one in the city and the other in the country, one in the tropics and the other in the Arctic regions, educate one and leave the other uneducated, we could determine just what are the effects on the individuals of such differences in environment. Of course, we can not cold-bloodedly separate infant twins and subject them to environmental extremes, but many equivalent experiments have been accidentally performed for us, and all we have to do is to determine the results. I mean to say that once in a while a pair of identical twins are left as orphans and are adopted one by one family and the other by another family. Such families may live in very different environments and the twins of a pair may be placed under very different living conditions, involving different social levels, different educational careers, and different sanitary or health conditions. These separated twins may also have very different experiences. When we discover such a pair of identical twins separated in infancy and reared apart, we realize that we have a rare and valuable experiment already performed for us that needs only careful study to give us valuable information about heredity and environment.

So far we have studied six cases of identical twins reared apart, and these have been compared with regard to their physical, mental and temperamental characters, and checked against the base line of the average differences of 50 pairs of identical twins reared together. The results so far indicate that the environment very distinctly modifies some physical characters such as weight, general health, etc., but does not alter others such as eye-color, hair color, teeth, features, etc. Moreover, the environment profoundly modifies those characters described by the terms "intelligence" and "personality." In some cases the intelligence of a pair of separated twins was three times as different as the average of 50 pairs of twins reared together. But after full credit is given to the modifying effect of the environment, the fact stands out sharply that hereditary resemblances remain most strikingly close. The six cases already studied of identical twins reared apart showed the following facts:—

Case I. A pair of twin young women, one with very much more formal education than the other, but with a much more varied social experience, showed after twenty-odd years of separation the following condition: They were practically identical physically and in intelligence, but were extremely different in temperament—in personality.

Case II. A pair of twin young women, one reared in London, England, and the other in a small Ontario town. They had about the same amount and kind of education. When tested, the colonial girl was very much more intelligent and in much better physical condition. In temperament—personality, they were extremely similar.

Case III. Two twin young women separated over 20 years, reared in about the same social and physical conditions, but one had far more education than the other. Physically and temperamentally they were extraordinarily similar, but the more educated twin was strikingly more intelligent.

Case IV. Two twin young men separated over 20 years, one reared in cities of some size, the other reared in country villages, both with high school education. The city boy was in much better physical condition and was slightly more intelligent. In temperament—personality—they were as utterly different as two persons chosen at random.

Case V. Two twin girls, separated for 28 years, but visiting each other from time to time. One has always lived on a farm, the other has lived in a small town and has spent most of her time indoors. The farm girl stopped school after the grades, the town girl went through high school and has studied music for 20 years. These girls differ equally strongly in all three respects: physically, intellectually and temperamentally. They show the most pronounced effects of environmental differences of any of the pairs studied.

Case VI. Twin girls, separated for 37 years, both married and with four and six children, respectively. One married a man who has always made a good deal of money, the other married a poor man. The life of one has been easy, that of the other very hard. Both nearly completed high school. There is very little difference between them in I. Q., only minor differences in temperament, but a very striking difference in physical condition. The twin who has had an easy life seems hardly over thirty while the one who has had a hard life seems eight or ten years older.

I earnestly wish we could find and study about four more cases such as these. If we had ten cases and they were as consistent as those already studied, we might be able to arrive at some very definite conclusions as to the relative effects of heredity and environment in producing human differences.

A great service would be rendered to science by any one who could give information about identical twins reared apart. If you know of any such cases please notify this station or write directly to Professor H. H. Newman, University of Chicago.

UNTANGLING ONE OF NATURE'S PUZZLES

By Professor B. SMITH HOPKINS

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MUCH of the chemist's work is concerned with the problem of the preparation of materials of known purity. Most of our naturally occurring raw materials are more or less complicated mixtures of substances whose properties are similar. If from these mixtures pure chemical materials are required, the work of purification frequently becomes the chief task in meeting the demands of modern civilization. For example, common salt, one of our most extensively used chemical materials, is found widely distributed in the earth's crust both in the form of brine and as crystalline rock salt. It is, however, rarely found free from admixture with other materials, such as rock, soil and especially other soluble compounds whose influence upon the salt is marked. Some of these compounds, like the bromides, give the salt a bitter taste, while others, like sodium sulfate, absorb moisture from the atmosphere and make the salt sticky or cause it to form a hard cake. For most purposes the removal of such impurities from the salt is demanded for very obvious reasons. Our modern standards are becoming more and more insistent that salt must be "all salt," and as a consequence the manufacturing chemist must continually improve his methods of purification. The rock and soil are easily removed by taking advantage of the fact that salt dissolves in water; consequently the simple process of filtering removes these impurities almost completely. Such treatment, however, will have very little influence upon the task of removing the soluble compounds.

In the purification of salt two general methods are available: (1) addition to the brine of some chemical substance which will change the soluble impurity to an insoluble form, thus permitting its removal by filtration; and (2) the evaporation of the brine under carefully determined conditions such that crystals of pure salt may be obtained while the undesirable impurities are separated. It is obvious that both of these steps must be taken with care, if they are to be successful. No material can be added to the brine to remove an impurity if the added substance will itself be objectionable. Moreover, the amount of the compound added in this way must be definitely determined in order that an excess may be avoided. In the purification by crystallization it must be remembered that under some circumstances the impurities will crystallize before or along with the salt. Consequently, the conditions must be controlled in such a way that the salt crystals may be separated as completely as possible from those substances whose removal is desired. One crystallization will never completely separate two soluble compounds, because the crystals which form first will always be wet with the solution of the other compound. Thorough washing of the crystals will aid materially in meeting this difficulty, and several repetitions of the crystallization process are effective in bringing about a reasonably complete separation. It is very obvious, however, that the preparation of chemically pure sodium chloride from such complicated mixtures of salts as are found in seawater is a task which presents difficulties of considerable proportions.

This simple illustration will serve to indicate the difficulties encountered in the chemist's perennial task of preparing a chemically pure substance from a naturally occurring raw material. It is true that nature in rare cases supplies us with material in a high state of purity. A clear water-white diamond represents one of the purest forms of carbon which is known, and crystals of clear quartz are pure silica, but these are exceptional forms of matter. Their adaptation to commercial uses requires such processes as cutting, polishing and grinding, with which the chemist is not concerned, since they are purely mechanical. At the opposite extreme we find many useful substances required in a high state of purity which are won from natural sources of a most unpromising character. During 1929 the world produced over two million tons of copper, most of which had a purity of at least 99.9 per cent. Some of this useful metal was obtained from ore which contained as little as one per cent. of copper. The world's production of gold in 1929 exceeded 400 million dollars in value, and part of this was obtained from ore which yielded as little as 1/20 oz. per ton of ore. It is also claimed that radium has been successfully won from ore so poor that one ounce of radium would require the concentration of all this precious metal that was contained in 10,000 tons of ore.

The production of high-grade copper for electric wiring from a low-grade ore represents a problem in intensive purification on a large scale. The concentration of high purity gold or of radium from their ordinary sources illustrates an extreme case of purification, in which the dross is truly enormous. Nature furnishes many puzzles in which we are challenged to separate a useful material from an almost overwhelming proportion of waste. Many of these problems have already been solved so successfully that the results command our respect and excite our admiration. But Mother Nature has given us many puzzles which have not yet been solved; these we are apt to regard with awe and dread, but if the object to be obtained is a desirable one they should challenge our intelligence and inspire an intensive effort for their solution.

One of the most puzzling problems in purification, certainly in the field of inorganic chemistry, is furnished by the group of elements commonly known as the rare earth group. This group may conveniently be thought of as a collection of at least 15 elements which through some fantasy of nature have been crowded into a space which is usually occupied by a single element. All the known elements are arranged in an orderly fashion in the systematic tabulation known as the Periodic Table. Throughout this table each element is given a single space; in a few cases three elements occupy one space and in the single instance of the rare earth group do we have more than three elements crowded together into one space. These 15 elements of the rare earth group are almost invariably all found together in the same minerals, and in addition there are two others which generally accompany them. To add to the complexity of this puzzle there are, in addition to the 17 elements which are generally thought of as comprising the rare earth group, at least a dozen closely related elements which are frequently present in rare earth ores. At least three or four of these closely related elements must always be expected in every rare earth ore, and it is not uncommon to find most of them present in a single ore.

Thus it appears that the rare earth group presents to the inorganic chemist a puzzle which is complicated in the extreme by the fact that the ores in which this group occurs contain from 15 to 20 or more elements. The untangling of so complicated a puzzle as this is in itself no simple task. But when attempts are made to solve this riddle other serious obstacles are immediately encountered. While some rare earth ores are available in large quantity at a reasonable cost, most of the minerals containing these compounds are scarce and difficult to obtain. As a consequence the initial cost of the raw material is generally high and the amount available at any price is definitely limited. When an adequate supply of ore is obtained difficulties are encountered because the minerals are refractory and yield reluctantly to chemical treatment. After the material is brought into solution and attempts are made to untangle the resulting complex mixture of salts by resolving it into a series of definite individual chemical compounds, new and perplexing obstacles are encountered. When an attempt is made to apply the methods of separation which are usually employed in the purification of a chemical mixture, extremely slow progress is made for the reason that the elements of this group are very closely related chemically. Any reagent which affects one will generally react with them all and to about the same degree. As a result special methods must be applied and the best of these are lamentably lacking in efficiency. As a consequence the most useful methods of purification which are now known are frightfully wasteful and wholly unsatisfactory.

Thus it appears that the process of untangling this complicated puzzle which nature has given us is difficult and expensive alike from the standpoint of time, money and patience. Some members of the rare earth group have been prepared in considerable quantity and in a high state of purity; these may now be purchased in the open market in large bulk and at a reasonable cost. Most of the individual members of the group have been prepared in a satisfactory state of purity, as a result of long, painstaking and patient effort. But some separations have never been accomplished completely, because several portions of the puzzle remain yet to be solved. For this reason the compounds of some of the rarer members of the group are almost or quite unattainable. With this situation in mind it is easy to understand why illinium, which appears to be the rarest member of the group, if not one of the rarest elements now known, escaped detection for so many years.

The method commonly employed in the separation of the members of this group are based upon one of two facts: (1) There is a gradual, though slight, change in the solubility of the salts of these metals and (2) there is a gradual decrease in the chemical activity of the metals as we proceed in regular order from the first to the last member of the group. According to the first fact, if we have a saturated solution of the bromates of the whole group and evaporate a part of the solvent it is obvious that some of the salts must crystallize out. If these crystals are examined and their composition compared with that of the mother liquor it is found that the crystals are richer in those members which are more difficultly soluble, while the solution contains a larger proportion of the more readily soluble compounds. If the process of partial crystallization is repeated with both the crystals and the solution, there will be still greater separations of the more difficultly soluble salts from those which are more readily kept in solution.

By repeating this process of fractional crystallization many hundreds of times, the original mixture of salts may be divided into a series of fractions, each one of which differs somewhat in composition from that of its neighbors. It is obvious, however, that complete separations of chemical individuals can not be expected by this method, since the differences in solubility are gradual and small. As a result fractional crytallization alone is rarely if ever depended upon to secure a chemically pure compound. The method works best for any salt which is either the most difficultly soluble or the most readily soluble of the series. Usually methods of fractional crystallization are employed as a means of splitting a large volume of a highly complex solution into a series of fractions, each of which is composed mainly of one or two individual compounds, with a small admixture of one or two of the most closely related compounds. In other words fractional crystallization is the first step in untangling the highly complex rare earth group.

Methods depending on the varying degree of chemical activity are of various types. If a precipitant like ammonia is added in excess to a mixed rare earth solution all the rare earth material would be precipitated. But if a very small amount of the precipitant is added only the weaker metals would be thrown out of solution. Similarly, if the mixed rare earth nitrates are heated, insoluble compounds are formed; but if the heating is carefully controlled only the weaker metals will be changed to the insoluble form. These and other similar methods are used to fractionate the relatively simple mixtures obtained by fractional crystallization. In general, a carefully manipulated combination of fractional crystallization and fractional precipitation or thermal decomposition will give the most satisfactory results yet obtained in the effort to untangle this rare earth puzzle.

Many other attempts have been made to find more satisfactory methods of separating the members of this group. In general they have not been as satisfactory as those which have been in use many years. New ideas are continually being developed and new methods of attack are being used. Progress is being made in the attempts to learn more about this intricate group. Probably the most valuable new method which has recently been used is that of electrolytic reduction, for which we are indebted to Professor L. F. Yntema. By this means he has prepared highly purified europium and ytterbium, two of the most rare and most difficultly separated members of the entire group.

Why should any one be interested in untangling so complicating a puzzle? What is to be gained from such work as this? Of what possible use is it all? Such questions as these force themselves upon us when we realize that a lifetime of hard work may be expended with apparently little actual progress. There are many reasons why the scientist persists in his efforts even in the presence of discouragement and disappointment. No one can predict in advance the value of any scientific investigation. Some of the world's greatest achievements have come from the most unexpected sources. Any effort which extends the boundaries of our intellectual horizon is worth while. To the worker in the field of the rare earths there is also the conviction that perhaps this group holds the key by which we may be able to unlock the storehouse of information of the whole periodic system.

If we can learn to understand the relationship of these elements to each other and to the more important commercial metals, it may be possible to use this information for a better understanding of those elements which we now consider commercially important. It is only by patient, persistent and devoted effort of this sort that scientific progress may be made. In addition the rare earth worker is stimulated by the conviction that the rare earth elements must have been put here for some specific use. It is only our own ignorance concerning them that makes them appear useless. Perhaps some one of them may prove to be extremely useful, as, for example, as a specific remedy for a baffling malignant disease. Surely no greater contribution to modern life could be desired than one which contributes definitely to the comfort, happiness, security and welfare of the human race.

CHEMICAL RESEARCH IN ICE MANUFACTURE[1]

By Professor D. B. KEYES

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IN considering the industrial growth of the country during the past twenty years it is interesting to discover that one of the major industries which developed during this period was the production of artificial ice. It is only possible to gain an accurate conception of the true proportions of this development by considering the fact that, during 1929, 54,000,000 tons of ice were produced, the retail value of which was approximately $400,000,000. Since, in addition to its size, the industry is intimately connected with the efficient maintenance of public health, its problems deserve particular attention in the form of effective research. In the past this attention has been centered in studies concerned with the efficient operation of the mechanical units comprising the refrigerating cycle. During a recent investigation conducted at the University of Illinois, however, problems more intimately concerned in the production of artificial ice itself have been made the basis of extensive research.

From a purely mechanical standpoint the manufacturing process itself does not involve an extremely involved procedure. A gaseous refrigerant, usually ammonia, is compressed to a liquid by means of mechanically operated compressors and is then allowed to boil at the expense of heat absorbed from a concentrated salt solution containing either sodium or calcium chloride, commonly called a brine, the freezing point of which is below that of pure water. Heat exchange is effected in an apparatus which effectively separates the two liquids by means of a metal wall. The ammonia vaporized during the process is again compressed, cooled in a water condenser and returned as a liquid to the evaporator, thus operating as a continuous, closed system. The net effect of using the refrigerant is to remove heat from the brine and to deliver the heat thus extracted to the condenser water used to cool the ammonia gas following its compression.

The brine, cooled by the removal of heat in the ammonia evaporator, is rapidly circulated past steel cans containing the water to be frozen. Ice is formed at the sides and bottom of the cans, thus leaving the unfrozen water confined in a core bounded by the growing walls of ice. When the water is completely frozen the cans are removed from the brine and placed in a thawing tank which is filled with warm water. Here a thin layer of ice is melted from the sides and bottom of the cans, thus allowing the ice to be removed when the cans are sufficiently inclined. The ice removed, the cans are refilled with water and returned to the freezing tank to yield another crop of ice.

The production of ice is thus seen to result from the expenditure of mechanical energy, the total work required being equivalent to that used by the compressors to return to its original liquid state the ammonia vaporized during the extraction of heat from the brine. In the original plants the only economical motive power available was that obtained from coal burned to produce steam, a procedure which fortunately served a double purpose, since the steam, after being passed through the compressors, was condensed to produce distilled water. When this water was quietly frozen in cans immersed in the freezing brine the ice produced was invariably transparent, due to the almost complete absence of dissolved salts. The effect of this practice was destined, however, to play an important rôle in the future economic development of the industry itself, for the consuming public finally arrived at the point where it definitely demanded the same degree of transparency that it had been early educated to expect.

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[1] This article is based on data previously published in Engineering Experiment Station Bulletin No. 219, "The Treatment of Water for Ice Manufacture," by Professor Dana Burks, Jr., Chemical Engineering Division, University of Illinois. Published by permission of Dean M. S. Ketchum, director of the Engineering Experiment Station, University of Illinois.

The full effect of this demand for transparent ice became apparent with the next major development affecting the industry. With general industrial growth it gradually became evident that power could be more economically produced in central power stations as electrical energy than in small individual steam installations. It was determined in the case of the ice industry, for example, that a ton of coal burned in a steam-driven ice plant would produce from four to six tons of ice while the same fuel burned in a central power station would generate sufficient electrical energy to produce from sixteen to eighteen tons when the operation of the plant was electrified. Electrification was determined to afford savings in ice production cost of from $0.40 to $1.00 per ton.

In the electrified ice plant, however, distilled water was no longer available for use in the freezing process. Natural water supplies had to be used in its place. Such supplies are unfortunately characterized by the presence of varying amounts of dissolved salts and when quietly frozen according to the procedure producing highly transparent ice in the distilled water plants result in a product which is completely opaque, as indicated in Fig. 1.

The reason for the production of opaque ice from solutions containing dissolved salts will be readily understood upon reviewing the conditions to which such solutions are subjected on being cooled. As the temperature is lowered a point is finally reached at which solid water or ice forms, and as heat continues to be absorbed from the solution the formation of ice continues. With the separation of water as ice, however, the salts present in the unfrozen solution are continually concentrated. With ice separating from a solution becoming increasingly more concentrated in dissolved salts a point is finally reached at which either of two

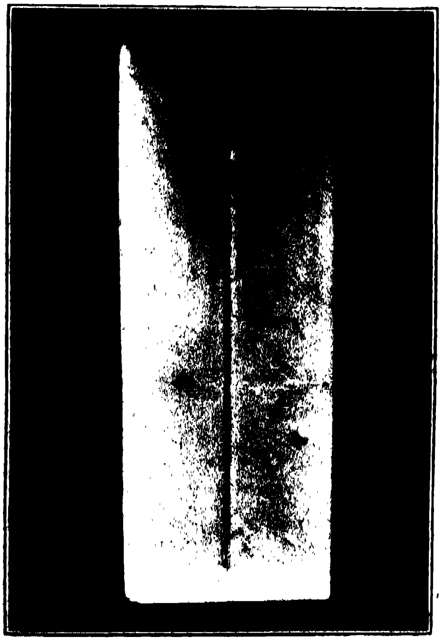


FIG. 1. ICE FROZEN FROM A SOLUTION CONTAINING DISSOLVED SALTS

UNDER CONDITIONS THAT INVARIABLY PRODUCE HIGHLY TRANSPARENT ICE WHEN THE SOLUTION BEING FROZEN IS DISTILLED WATER AND THEREFORE FREE FROM SALTS. THIS ICE IS COMPLETELY OPAQUE, OPACITY HAVING RESULTED FROM THE FACT THAT ITS OPTICAL PROPERTIES HAVE BEEN MATERIALLY AFFECTED BY THE PRESENCE OF THE DISSOLVED SALTS IN THE WATER FROM WHICH THE ICE CRYSTALS FORMED.

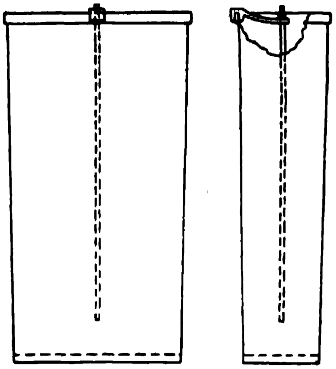


FIG. 2. A TYPICAL METHOD OF APPLYING AIR

TO OBTAIN AGITATION OF THE SOLUTIONS BEING FROZEN ACCORDING TO PROCEDURE WHICH HAS BECOME STANDARDIZED IN THE ICE INDUSTRY. THE AIR ENTERS THE SOLUTION AT A SINGLE POINT, AND MAXIMUM AGITATION RESULTS IN THE CENTER OF THE SOLUTION. WHEN THE INITIAL SALT CONCENTRATION AND THE RATE OF CRYSTALLIZATION ARE HIGH, SUCH AGITATION IS INEFFECTIVE IN PREVENTING THE FORMATION OF OPAQUE ICE AT THE FREEZING SURFACE WHERE THE DISSOLVED SALT HAS A TENDENCY TO CONCENTRATE LOCALLY.

conditions occasioning the formation of opaque ice results.

If the composition of the original solution is such that an insoluble compound may be formed as the result of concentration, solid salt will eventually separate with the ice as an eutectic mixture. Due to the fact that an eutectic generally possesses optical properties which differ from those of pure ice alone the solid will appear opaque. A further disadvantage of the separation of an eutectic mixture lies in the fact that when the ice melts the salt does not redissolve but remains behind as an insoluble sludge, a sludge which either clogs up the drain in the domestic ice box or coats the produce which it is used to cool during shipment to market. The separation of salt with the ice may be effectively prevented, however, by treating the water chemically before it is frozen so that the salts of low solubility are converted into more soluble compounds. This may be effected, for example, by neutralization of the carbonates of calcium and magnesium to the corresponding sulphates, a process commonly accomplished in practice by means of aluminum sulphate.

The second condition occasioning the formation of opaque ice results when the dissolved salts become sufficiently concentrated to affect the physical characteristics of the individual ice crystals themselves. The environment from which a crystal forms exerts a decided effect on both its habit and orientation. When these properties become materially altered, light passing through the solid is sufficiently scattered to cause the mass to appear

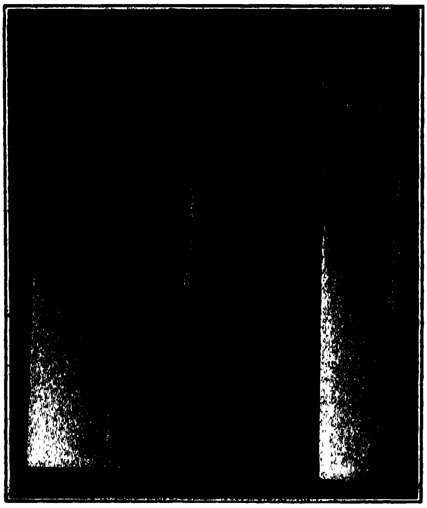


FIG. 3. ICE FROM A SOLUTION CONTAINING A HIGH CONCENTRATION OF DISSOLVED SALTS

FROZEN UNDER CONDITIONS RESULTING FROM AIR AGITATION APPLIED ACCORDING TO THE METHOD ILLUSTRATED IN FIG. 2. THE OPAQUE SHELL ENCASING THE ICE CAKE AND THE THICK OPAQUE CORE ARE TYPICAL RESULTS OF INEFFECTIVE AGITATION. ICE OF THIS QUALITY IS THOROUGHLY UNMARKETABLE. IN THE PAST THE ONLY REMEDY FOR THIS CONDITION HAS BEEN TO DISTIL THE WATER TO REMOVE THE SALTS. SUCH PROCEDURE PREVENTS THE ELECTRIFICATION OF THE MANUFACTURING PROCESS AND MATERIALLY INCREASES THE COST OF PRODUCTION.

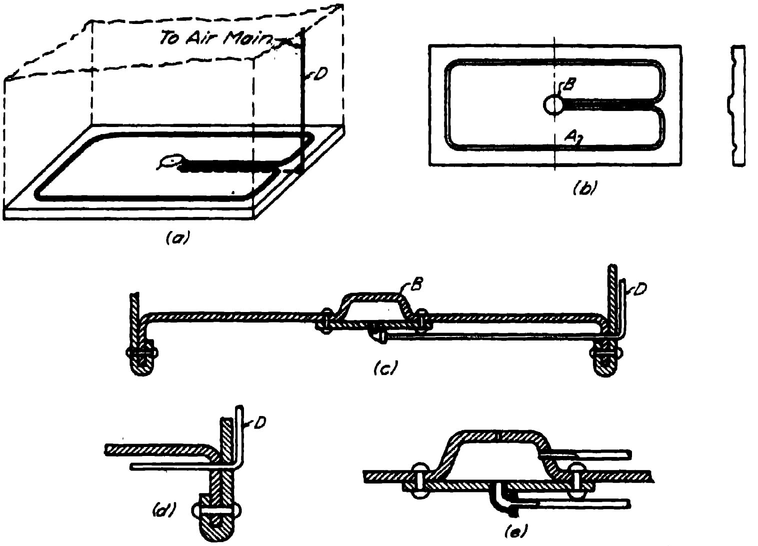


FIG. 4. DETAILS OF THE NEW TYPE OF ICE CAN

DEVELOPED AT THE UNIVERSITY OF ILLINOIS. THE AIR FOR AGITATION IS FORCED TO ENTER THE SOLUTION THROUGH A SERIES OF SMALL HOLES IN A HEADER LOCATED AT THE EXTREME SIDES OF THE CAN AS INDICATED IN (a). THE ICE WHICH INITIALLY FORMS WHILE THE RATE OF CRYSTALLIZATION IS HIGH IS THUS EFFECTIVELY AGITATED. WHEN THE RATE OF CRYSTALLIZATION IS MATERIALLY REDUCED BY THE FORMATION OF A SUFFICIENTLY THICK LAYER OF ICE THROUGH WHICH HEAT MUST BE REMOVED BY THE BRINE, A MUCH SMALLER AMOUNT OF AIR APPLIED FROM A POINT LOCATED CENTRALLY IN THE CAN AT B IN (b) IS SUFFICIENT TO PREVENT THE FORMATION OF OPAQUE ICE. WHEN THE AIR SUPPLY IS REDUCED, ICE FORMING IN FROM THE SIDES OF THE CAN EFFECTIVELY PLUGS THE HOLES IN THE OUTER HEADER AND ALLOWS THE FINAL AIR TO ENTER ONLY FROM THE HOLE AT B. DETAILS OF THE CAN'S CONSTRUCTION ARE INDICATED IN (c), (d) AND (e).

opaque. The general phenomenon is quite common. For example, a large transparent crystal on being pulverized is reduced to a mass which appears opaque, even though the individual crystal units themselves remain perfectly transparent.

To overcome the formation of opacity from this cause, any localized salt concentration at the surface of the growing crystal must be prevented and the unfrozen solution must be removed whenever the salts become concentrated to the point where the orientation and habit of the ice crystals are affected. Removal of the unfrozen core water obviously necessitates refilling the core cavity with a fresh supply of the water originally used.

When the salt solution is first subjected to freezing, extremely rapid cooling takes place at the sides of the metal can. This results from the fact that the heat conductivity of steel is comparatively high, and that the freezing brine in the average plant is maintained at a temperature 16° F. below that at which ice initially forms. The rate at which the first ice makes its appearance must, therefore, be exceedingly high.

This layer of ice which initially forms is, of course, surrounded by all of the unfrozen solution. Actually, however, it may be considered to be bounded by only a thin film of the salt solution. It is, therefore, the conditions existing in this fluid film which not only affect the physical characteristics of the crystal, but also determine the physical characteristics of the final cake of ice. Since growth of the ice surface depends upon its continued ability to remove water

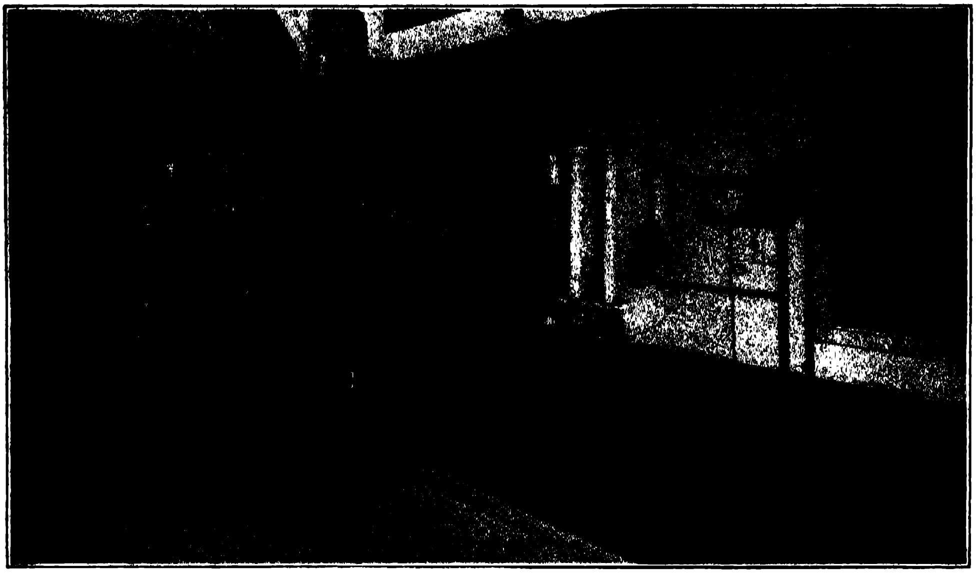


FIG. 5. DETAILS OF THE EXPERIMENTAL ICE PLANT

RECENTLY INSTALLED AT THE UNIVERSITY OF ILLINOIS TO FACILITATE FURTHER INVESTIGATION OF PROBLEMS INVOLVED IN THE EFFICIENT MANUFACTURE OF ARTIFICIAL ICE.

from this fluid film, a decided tendency exists for the salts present in the film to become locally concentrated, the extent of this tendency being dependent upon the initial concentration of the salts in the solution and the rate at which ice is formed at the crystal face. Unless local concentration of the salt is effectively prevented the critical concentration affecting crystal orientation may be reached in the film long before the concentration of the salts in the main body of the unfrozen solution becomes materially altered.

The most effective way to prevent local concentration in the surface film is to agitate the solution as it is being frozen. By agitation the concentrated salt solution formed in the fluid film is mixed with the main body of the solution which is more dilute. In common practice agitation is accomplished by expanding air under pressure into the bottom of the cans filled with water. In rising to the surface the air imparts a certain degree of motion to the liquid which in turn results in the desired mixing. In the past, however, the agitation developed by means of air has been relatively inefficient. The air has been delivered to a single point located near the center of the bottom of the can, as indicated in Fig. 2. As a result the effective movement of the liquid exists in the form of an inverted cone whose apex corresponds to the point of entry of the air. The maximum agitation results not at the sides of the can but in the center. It is at the sides, however, where the most effective agitation is needed and especially is this true during the initial freezing period. An example of inefficient agitation in cases where the initial salt concentration of the water being frozen is high is shown in Fig. 3. As a result of such procedure it has in the past been considered impossible to produce marketable ice from raw water sources containing salts in excess of 600 to 700 parts per million.

During the course of the present investigation a new type of freezing can has been developed whereby the efficiency of the air agitation imparted to the solution is greatly increased. The construction of the new can is indicated in Fig. 4. The air is forced to enter at the extreme sides of the can, thus causing maximum agitation to always exist at the surface of the ice. In Fig. 6 is shown the result of using the new can in freezing the water which produced, under standard freezing procedure, the thoroughly unmarketable product shown in Fig. 3. For comparison ice frozen from distilled water is shown in Fig. 7.

As a result of the present investigation, it has been determined on the basis of both laboratory and plant scale operations that thoroughly marketable ice can be made from any natural water source which may be considered as an industrial supply. It is, therefore, no longer necessary to distil water in order to render it suitable for use in the production of marketable ice. Approximately one third of the ice produced is still being manufactured in steam plants in the face of the lower operating cost which electrification offers. Undoubtedly factors other than the inability to produce marketable ice in electrified production exist in many steam installations. The steam generating equipment, for example, may have been so recently installed that the depreciation loss incurred by its removal can not yet be economically absorbed. As the result of the present investigation, however, control of the physical and chemical conditions at the surface of the growing ice crystal has been shown to be sufficient to produce clear, transparent ice in electrified plants, whenever desired, from any natural water found in the United States.

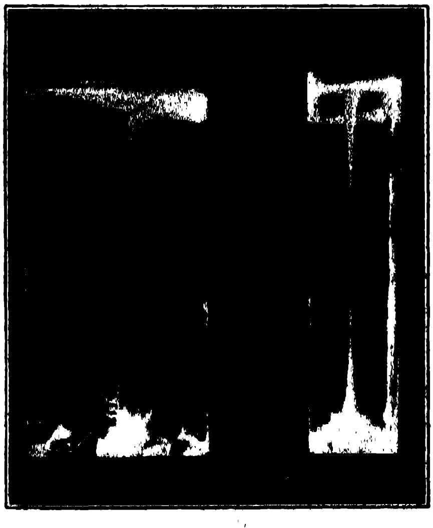


FIG. 6. ICE FROM THE SAME WATER WHICH PRODUCED THE UNMARKETABLE PRODUCT SHOWN IN FIG. 3

FROZEN IN THE NEW TYPE OF ICE CAN SHOWN IN FIG. 4. IN ORDER TO JUDGE THE QUALITY OF THIS ICE FROM THE STANDPOINT OF TRANSPARENCY, REFERENCE SHOULD BE MADE TO FIG. 7, WHICH INDICATES THE ICE PRODUCED FROM DISTILLED WATER AGITATED BY AIR DURING THE FREEZING OPERATION.

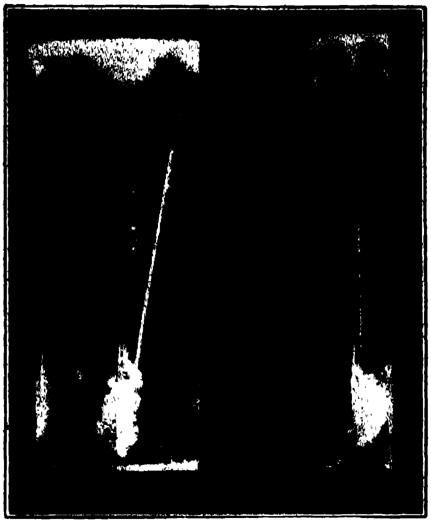
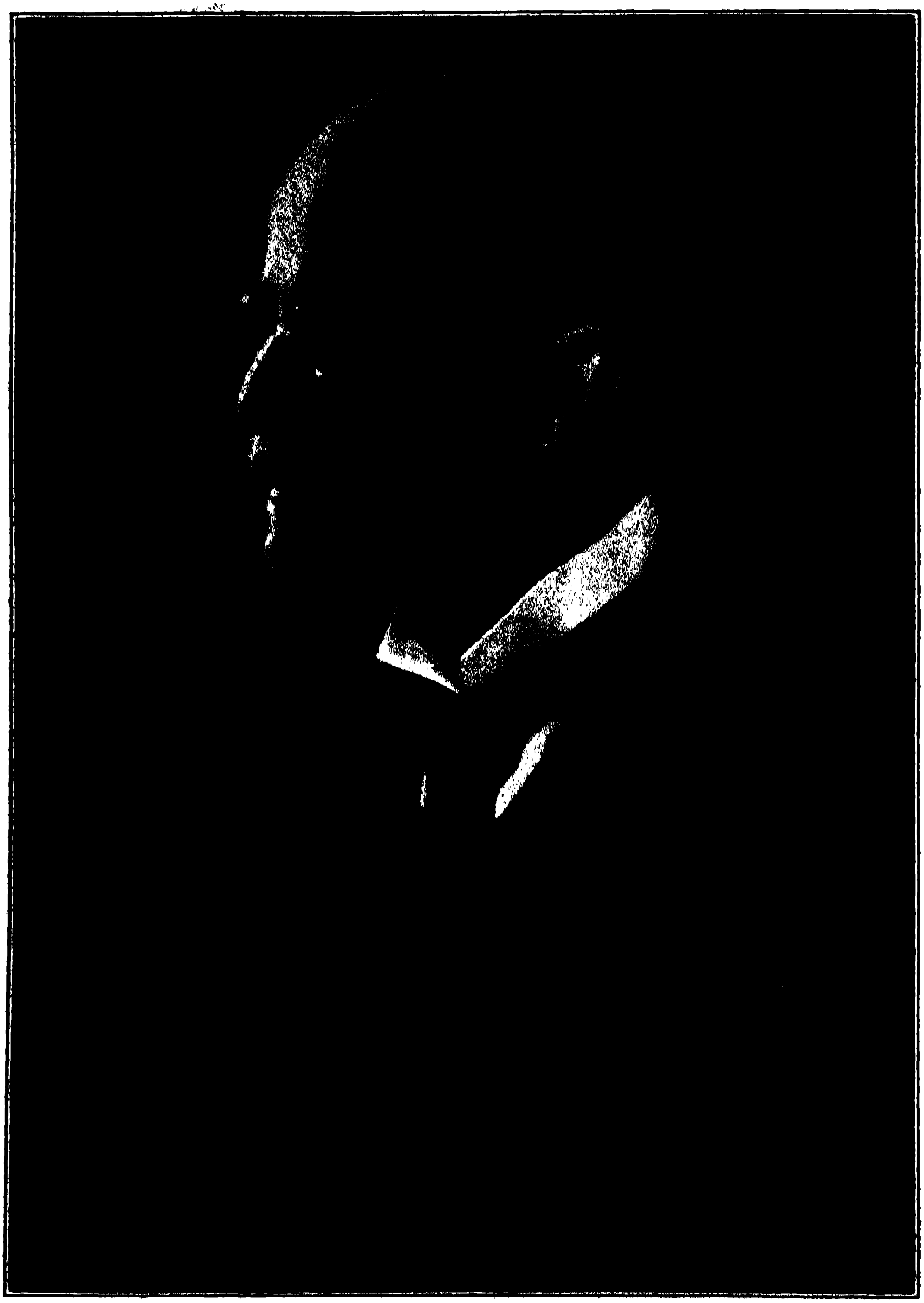


FIG. 7. ICE FROZEN FROM DISTILLED WATER

AGITATED BY MEANS OF AIR THROUGHOUT THE FREEZING OPERATION. OPACITY IN THIS CASE RESULTS FROM THE FACT THAT THE FINAL WATER WHICH FREEZES IS WHIPPED INTO AND FREEZES AS AN AIR FOAM, THE OPTICAL PROPERTIES OF WHICH DIFFER SUFFICIENTLY FROM THOSE OF ICE ALONE TO CAUSE LIGHT PASSING THROUGH THE ICE CAKE TO BE MATERIALLY SCATTERED.



PROFESSOR JOHN J. ABEL

PRESIDENT OF THE AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE.

THE PROGRESS OF SCIENCE

PROFESSOR JOHN J. ABEL: PRESIDENT OF THE AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE

THE election to the presidency of an organization so thoroughly representative of the numerous branches of science as the American Association for the Advancement of Science is a public recognition that the person so honored is possessed of very high cultural and scientific qualifications and has made notable contributions in his chosen fields of interest. In electing Professor Abel as its president the association has not only conferred a well-merited honor on him, but it has also recognized him as a leader and distinguished contributor to science.

John Jacob Abel was born on May 19, 1857, and was brought up on a farm near Cleveland. As a child he showed a keen desire for learning and at the age of nineteen he entered the University of Michigan. He received his Ph.B. degree from this institution in 1883 after an interruption of three years, during which he taught Latin, mathematics, physics and chemistry at La Porte, Indiana. He then went to the Johns Hopkins University for a year of graduate study in physiology and biology.

That Professor Abel had the correct conception of the real nature and purpose of scientific medicine is evidenced by the fact that when, fifty years ago, he decided to make this his life work he was one of the very few medical men of his day who submitted himself to a long and thorough training in fundamental branches. From the fall of 1882 to January, 1891, when he was called to his alma mater (University of Michigan) as professor of materia medica and therapeutics (a title which is equivalent to that of professor of pharmacology) he spent nine years in intensive studies in physiology, chemistry, biochemistry, pharmacology and medicine in order properly to prepare himself as an investigator and teacher. Of this period one year was spent as a graduate student at the Johns Hopkins as already stated and six and a half years, from the summer of 1884 to January, 1891, in the Universities of Leipzig, Strassburg, Heidelberg, Berne and Vienna, with vacation studies in Würzburg, Berlin and Paris. Throughout these years, as I know from conversations with him, his mind was occupied with fundamental questions of a kind that must always underlie fruitful work in the biological and medical sciences. He chose to study under such great leaders as Carl Ludwig, Schmiedeberg, Hoppe-Seyler, Drechsel, von Nencki and Wislicenus in the fields of physiology, pharmacology, biochemistry and chemistry, and he enrolled himself as one of their pupils, both in the laboratory and in the lecture room. Then, too, the lectures and the ward rounds with famous clinicians, such as Strümpell, Wagner, Kussmaul and later Naunyn, not to forget Naunyn's associates, von Mering and Minkowski, Erb and Nothnagel and others aroused in him an interest in clinical medicine as taught by these men, who had themselves made important discoveries. The pathologists v. Recklinghausen and Arnold, neurologists of the older generation such as Meynert, great surgeons and many other leaders in the more special branches of medicine contributed to the broadening of outlook in the young man. In 1888 he took his examinations for the M.D. degree, in preference to the Ph.D. degree, at Strassburg, at that time a great German imperial university. The next two years he spent in graduate work at the University of Vienna and Berne, working at the latter university in the laboratory of the distinguished biochemist von Nencki, a pupil of Adolf Bayer.

In 1892, after two years as professor at the University of Michigan, Abel was called to the chair of pharmacology in the Johns Hopkins University, and he entered on his duties at the opening of the medical school here in 1893. As no professor of physiological chemistry had been appointed he was asked to give lectures and to supervise the laboratory work in that field, and for fifteen years thereafter the two departments—physiological chemistry and pharmacology—were both under his direction.

In the early years of the medical school some of Abel's work was of a purely biochemical character as, for example, his isolation of ethyl sulphide from among the products secreted by the dog's kidney and his study of the volatile mercaptans of the secretion of the common skunk. His familiarity with both stable and unstable aliphatic sulphur compounds of the animal organism bore fruit many years later, when in 1925 he and the writer were working on the purification of crude insulin extracts as guest research workers in the Gates Chemical Laboratory of the California Institute of Technology at Pasadena, California. Here Abel observed that all active fractions of insulin preparations contained labile sulphur in proportion to their blood-sugar lowering power, and this proved to be the clue which led to his subsequent successful crystallization of insulin.

Very early in his career he took up chemical and physiological studies of those important and elusive products of internal secretion, now known as hormones, of which "the race is both the beneficiary and the victim" (Barker). In 1895 he began work on the isolation of the extraordinary blood pressure raising hormone elaborated in the medullary portion of the suprarenal glands. A number of years were devoted to this problem with the result that the active principle was obtained in the form of a monobenzoyl derivative which Abel named epinephrine. Later Takamine obtained the free base, adrenaline, by omitting benzoylation, and precipitating out the base from very concentrated solutions with ammonia. Abel's early publications on his pioneer work in this field have been followed by thousands of papers by other investigators dealing with the physiological action, medical uses, chemical constitution and synthesis of this hormone. Years later (1911–1913) Abel came upon this compound again as a constituent of the creamy secretion of the skin glands of the large tropical toad, *Bufo Agua*. This toad not only produces epinephrine or adrenaline in its suprarenal organs, but has a large amount of this substance in its skin glands, amounting to 6 per cent. of the moist secretion. We have here the first example of an internal secretion or hormone which also appears as a protective poison in an external or skin secretion. After many previous workers had failed, Abel succeeded in isolating another crystalline compound, bufagin, from this toad skin secretion. It is a powerful heart stimulant, equally as powerful as and similar in action to the well-known digitalis.

With W. W. Ford from 1906 to 1908 researches were undertaken on the active principles of the poisonous mushroom, *Amanita phalloides,* known in French literature as "the destroying angel." Ford had shown in animal experiments that this fungus contains two separate principles of unknown character and composition, one a hemolysin and the other a non-hemolytic toxin. The hemolysin was isolated by Abel and Ford, although not in crystalline form, and found to be a nitrogenous sulphur-containing glucoside. The deadly constituent of the fungus, the toxin, was also isolated as a stable chemically indifferent compound containing both nitrogen and sulphur. This toxin accounts fully for the lethal character of this fungus when ingested. The glucosidal constituent, Amanita-hemolysin, had previously been shown by Ford to have the properties of an antigen, that is to say, animals that had been prepared by small injections showed definite amounts of antihemolysin in their blood. These studies were also of importance, since both products, as isolated by Abel and Ford, were definitely shown not to be toxic albumins, as had been assumed by earlier investigators.

Another series of Abel's investigations lies in the field of chemotherapy. In conjunction with Rowntree studies were carried on from 1909 to 1910 on the efficacy of antimony thioglycolic acid compounds in the treatment of experimental trypanosomiasis. In this connection Abel prepared a new compound, the triamide of antimony thioglycolic acid, by an interesting synthesis. This compound, like sodium antimony thioglycolate, was found to be very effective in experimental trypanosomiasis and has now found a use in the treatment of the tropical disease known as *granuloma inguinale* and of Bilharzia.

Another line of work was undertaken in collaboration with Rowntree. Surgeons had called Abel's attention to their great need for a purgative that could be given after operations, especially laparotomies, by subcutaneous or intramuscular injection. Abel began studies of various phthalein derivatives with this point of view. The objective in this research was not attained, but findings of great value to medicine nevertheless resulted from these investigations. Abel and Rowntree found that phenolsulphonephthalein was excreted solely by the kidney, and since its introduction in 1910 into clinical medicine by Rowntree and Geraghty this agent has been used in many clinics as one of the most valuable tests for the functional power of the kidneys. The halogen substitution products of phenolphthalein—phenoltetrachlorphthalein and tetrabromphenoltetrachlorphthalein—were found to be excreted in the bile only, and this fact led to the development of tests for liver function by the use of these and similar compounds.

Then came the period of the researches on vividiffusion. Abel devised a simple apparatus and a method by which the blood from a living animal could be deflected from the body, passed through a dialyzing apparatus, and then returned to the body. In passing through the dialysis tubes of the apparatus the flowing blood rids itself of diffusible bodies of all kinds while retaining its blood corpuscles and large protein molecules. With this apparatus it was demonstrated for the first time by the free passage of amino acids through the membranes that these acids and also sugar, various oxyacids, some ferments, odoriferous constituents, as ethyl sulphide, and so on, exist in the blood in the free state and not in some firm combination, as say in peptide form, for amino acids, or, in some other form of union, as was suggested in the case of sugar. At least one new compound was isolated by Abel from the dialyzates of the blood of living dogs, namely, α-isobutylhydantoin ($C_7H_{12}N_2O$). The apparatus used in these vividiffusion experiments has often been referred to as an artificial kidney. Of course, it differs from a real kidney in exercising no selection in removing diffusible substances from the blood. It is, however, an easy matter to prevent the removal of any given substance, as, say, sugar, from the blood, by having an equal concentration of it in the saline on the outer side of the tubes. The apparatus has been used by many investigators for one purpose or another since it was first described, and the clinician Professor Georg Haas, of Giessen, has applied it with modified technique to human beings gravely ill with glomerulo-nephritis; he has been able to alleviate their symptoms for five or six days at a time when their blood again accumulated the various organic principles that their diseased kidneys can not eliminate.

Among other fields of work coming within the range of Abel's scientific activity are the action of various dyestuffs in causing convulsions in frogs under various conditions, studies on the lymph hearts of frogs, studies in plasmaphaeresis, proof that proteoses exist in the free state in all the organs of the body as integral constituents of their cells or tissue spaces; that proteoses are not present in the blood in the free state, although they dialyze through membranes, but circulate as a compound or compounds of proteose and protein; that histamine is widely distributed throughout the organs of the body either as such but more probably in the form of a labile precursor; that the posterior lobe of the pituitary gland throws out its highly active constituents not as separate individuals but in the form of a unitary hormone. These researches which can be only alluded to here have given rise to an extensive literature often controversial in character.

One of Abel's major achievements remains to be described, namely, his separation and isolation in 1926 of the pancreatic hormone, insulin, as a beautifully crystalline compound from its admixture with proteins and other inert constituents in pancreatic extracts. It is characterized by a relatively high sulphur content and marked instability toward many chemical reagents and is destroyed by the ferments of the intestinal tract, and hence can not be administered by mouth. This is the first example of the isolation of an internal secretion product or hormone that must be classed with the proteins. It is another example among many of the production by one of our tissues of a powerful drug with quite specific actions; indispensable for health, but fatal in overdose, unless promptly antagonized by glucose. The true significance of this discovery, and the large amount of work that has followed from it in his laboratory as well as other laboratories can not be elaborated on here.

Not least among the contributions of Professor Abel to the advancement of the biological sciences is the founding of the *Journal of Biological Chemistry* with the late Dr. Christian A. Herter in 1905, and the *Journal of Pharmacology and Experimental Therapeutics* in 1909, which he still edits in association with Professor J. A. Gunn, of Oxford University in England.

Honorary degrees have been awarded Professor Abel by a number of leading universities in this country and in Europe. He has also been the recipient of several medals and prizes both here and abroad. He holds membership in many learned societies and honorary membership in seven foreign scientific societies and academies.

Professor Abel has a long list of pupils, many of whom hold professorships here and abroad and have attained distinction. A number of them have at one time or another during their period of apprenticeship assisted in carrying on the above researches, but always they have been urged to try their hand at problems of their own devising. Thus encouraged and supported by the master and spurred on by the example constantly before them of his own indomitable enthusiasm and unquenchable devotion to research, Professor Abel's many associates have made important contributions from his laboratory during the past forty years. Any one who will read his address on the "Education of the Superior Student" which appeared in the *Journal of Chemical Education* will find the secret of his influence on young men.

E. M. K. Geiling

THE SECOND NEW ORLEANS MEETING OF THE AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE

To understand America without some personal acquaintance with the historic city of New Orleans is quite impossible. New Orleans is the least American of all our cities. It is exceptionally interesting for the picturesqueness of its older sections, and for the language, tastes and customs of a large portion of its people. It is as unique as the dark wet cypress forest draped with long pendent Spanish moss that once occupied its site, and which still encircles, more or less, its low horizon.

New Orleans is not so very old, but it has had a most romantic history. It was founded in 1718 by Jean Baptiste Lemoyne de Bienville, a French Canadian. A few years after its founding, when it was still a squalid village, it was made the capital of that vast Louisiana which vaguely included the entire Mississippi valley northward to Canada and extended westward no one knew how far.

In 1768, when the population had increased to about 3,200, the inhabitants of New Orleans and of the surrounding countryside mustered under arms almost to a man, refusing to accept the cession to Spain of Louisiana. By their show of unexpected force they compelled the holder of the Spanish king's commission to return to Havana. But in the following year Don Alexandro O'Reilly landed a formidable force of Spanish troops and took the city.

On November 30, 1803, the aged Spanish governor Salcedo handed the keys of the city back to the representatives of the French government. Twenty days afterwards, with similar ceremonies, the keys of the city passed from the hands of the French colonial prefect to those of the commissioners for the United States.

In this historic setting was held the eighty-ninth meeting of the association. And, strange to say, there was no disharmony between the meeting and the local background. For New Orleans has kept pace with modern progress. Energy and resourcefulness have created a thoroughly modern city able to hold its own with any other, yet at the same time constantly mindful of its romantic past.

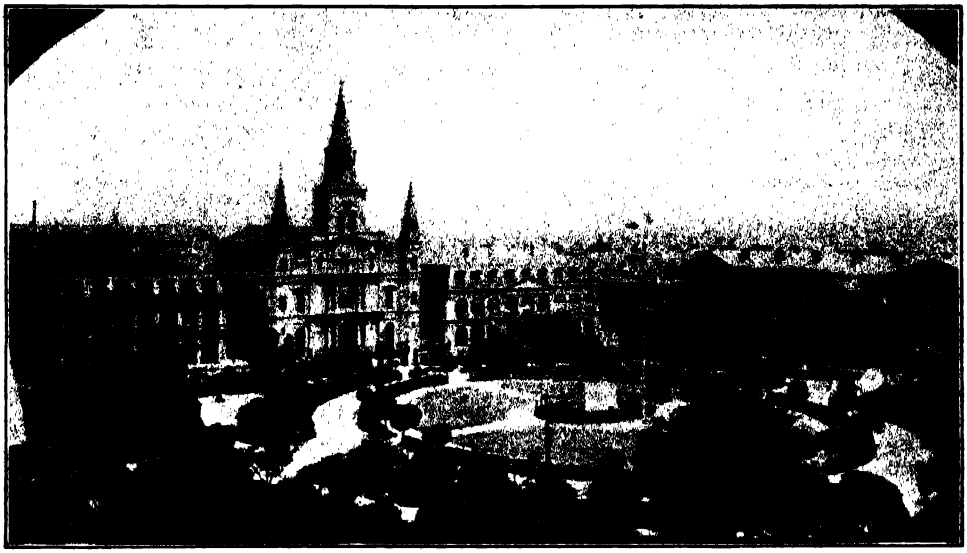
Modern New Orleans was seen at its very best in everything connected with the meeting.

The local committee, under the guidance of Dr. Daniel S. Elliott, of Tulane University, carried out its work in the most thorough, energetic and efficient manner. It functioned throughout as a closely knit unit. Every problem that came before it was examined and analyzed and accorded its proper weight and place in the general scheme. In the earlier stages of its work the committee met once a week, later meeting oftener when necessary.

It is no exaggeration to say that as a result of the work of this committee the arrangements made to care for all the numerous divisions and subdivisions of the meeting were as nearly perfect as it was possible to make them. Many considered them quite perfect. All agreed that they were much superior to anything in the previous experience of the association.

The weather at New Orleans during the meeting seemed to have been planned as carefully as everything else. All the days were sunny, and all were summerlike, with a maximum temperature of 84°. About the open places in the city, especially about the Municipal Auditorium, and even in the busy city streets themselves there occasionally appeared conspicuous yellow butterflies, most unusual accompaniments of a winter meeting.

The entertainment program arranged by a special entertainment committee, of which Dr. Marten ten Hoor was chairman, was varied and most interesting.



THE PLACE D'ARMES
THE HEART OF OLD NEW ORLEANS, LAID OUT BY BIENVILLE IN 1718.

Many excursions were planned to places of interest both within and without the city. No American city offers so much that is unusual to the average American as New Orleans. The old French, Spanish and Creole quarter, known as the Vieux Carré, is especially attractive because of its Old World atmosphere, its narrow streets, its picturesque buildings, its galleries with their decorative wrought-iron railings and its beautiful courtyards. It is one of the few spots in the United States where international history has been made. It was in this quarter that the drama of the Spanish and French occupation, with its successive shifting of political, racial and cultural emphasis, was staged. In spite of the great changes that have occurred, the atmosphere of those days still remains. For this reason the Vieux Carré is today the favorite rendezvous of those painters, musicians and writers who either live in New Orleans or go there to spend the winter.

The country about New Orleans is as interesting and unusual as the city itself, and the trips to various places outside the city proved very popular. Every one who participated spoke very appreciatively of these excursions, which were well chosen and admirably conducted.

In addition to the out-of-doors excursions, a number of most delightful teas and other entertainments were arranged by the committee of hostesses, of which Mrs. A. B. Dinwiddie was chairman.

The attendance at the meeting was larger than had been expected. About 1,450 registered, but many attended who did not register. For instance, the meetings of the Wilson Ornithological Club averaged between 75 and 80 participants, none of whom registered. It is probably safe to say that the actual attendance was roughly double the registration figure.

The evening addresses proved very popular, the audiences numbering between 1,500 and 1,800 for each. Such a large attendance as this is quite exceptional and probably resulted, at least in part, from the advance distribution of about 12,000 tickets, and also from the closing of the exhibit in the same building just before each address.

The meeting was opened on Monday evening by the general chairman of the

GIBSON HALL
THE ADMINISTRATION BUILDING OF TULANE UNIVERSITY.

New Orleans Committee on Arrangements for the meeting, Dr. Daniel S. Elliott, of Tulane University. In a short address Dr. Elliott introduced Dr. Elmer D. Merrill who, in the absence of Professor Franz Boas, the president, and Dr. Bergen Davis, the senior vice-president, served as the presiding officer. Dr. Merrill introduced Dr. Robert A. Millikan, who responded to words of welcome by President A. B. Dinwiddie, of Tulane University, and by Dr. Frank R. Gomila, representing Mayor T. Semmes Walmsley, of New Orleans, and then presented the speaker of the evening, Dr. Richard P. Strong, of the Harvard University Medical School.

Dr. Strong outlined our present knowledge, in no small part the result of his own work, of various filarial "worms" which are responsible for certain distressing and often very serious ailments in tropical and subtropical regions. Following Dr. Strong's address there was a reception held in the Auditorium.

On Tuesday evening came the lecture of the Sigma Xi. This was given by Mr. C. F. Hirshfeld, of the Detroit Edison Company, who discussed the proper allocation of the responsibility for certain happenings and conditions in the affairs of men. Problems arising from the application of science to industrial life were treated from the point of view of an engineer who is engaged in the work of furthering applied science.

For Wednesday evening a program was arranged in memory of Thomas Alva Edison, who was one of the founders of the association's official organ *Science*. After an appreciation of Mr. Edison based on personal acquaintance by Dr. Charles L. Edgar, president of the Edison Electric Illuminating Company of Boston, there were two addresses on Edison's contributions to science and industry, one by Dr. Frank B. Jewett, vice-president of the American Telephone and Telegraph Company, and the other by Dr. Robert A. Millikan, director of the Norman Bridge Laboratory of Physics, California Institute of Technology. These addresses were followed by a description of Edison's laboratory in war time by Dr. Karl T. Compton, president of the Massachusetts Institute of Technology.

On Thursday evening many important problems connected with the control of the Mississippi River were discussed by Mr. Floyd A. Nagler, of the Iowa State University.

SCIENTIFIC EXHIBIT IN THE AUDITORIUM
WHICH ATTRACTED SOME 18,000 VISITORS.

The address on Friday evening was by Professor Irving Fisher, of Yale University, who discussed the causes of the present world depression, repeating the substance of his address in a radio talk immediately afterwards.

The scientific program was more extensive than had been anticipated. About 1,300 addresses and papers were presented—several hundred more than the number expected. The surprising thing about the papers, however, was not their number but their quality. The proportion of contributions, including material of unusual interest and value and written and delivered in a clear and lucid manner, was considerably greater than it has been at any meeting heretofore. The reason for this is not at first sight evident, and indeed is immaterial. For several years there has been noted a constant and continuous improvement in the programs. It would seem that the members are coming to the conclusion that the meetings of the association provide the best and most appropriate setting for the first announcement of new discoveries and new ideas.

A special feature of the meeting was the relatively large number of invited papers, covering a broad range of subjects, and particularly of invited papers arranged in symposia. Of these symposia the joint session of the physicists and mathematicians was perhaps the most noteworthy.

No other token of recognition of scientific merit in this country is of such widespread interest to the public as the annual award of the association's $1,000 prize for a noteworthy paper presented at the meeting. At the New Orleans meeting this prize was awarded to Dr. Carl Caskey Speidel, of the University of Virginia Medical School, for his paper on "Studies of Living Nerves. II. Activities of Ameboid Growth Cones, Sheath Cells, and Myelin Segments, as Revealed by Prolonged Observations of Individual Fibers in Frog Tadpoles."

Dr. Speidel's paper was remarkable not only for its unusually high scientific value, but also for simplicity and clarity of expression. He knew exactly what he wished to say and said it in a way that any one with a reasonable education and some knowledge of biology could understand. It was received by the Press Service well in advance of the meeting. So important did it seem to the press representatives that it was mentioned as a leading contribution to the scientific program of the meeting in Tuesday afternoon and Wednesday morning papers.

It is a real pleasure to be able to say that Dr. Speidel's long-continued, painstaking and brilliant work was appraised at its true value both by his scientific colleagues and by those who interpret our meetings for the benefit of the public at large.

A scientific meeting would be sadly incomplete if the participants confined themselves to imparting information through the ear alone. Many people prefer to acquire information through the eye, or at least are not quite satisfied unless both ear and eye receive their share.

One of the most distinctive features of the New Orleans meeting was the extraordinary series of scientific exhibits brought together through the efforts of a special committee, of which Dr. Fay C. Brown was chairman and Mr. Owen Cattell was secretary.

These exhibits were so very diversified that every one, no matter in what field his interests lay, found something fascinating. There was a collection of copies of documents relating to the Louisiana purchase, a demonstration of the physiological changes that occur with fatigue, a booth showing the beaver at home, a special depicting of the Federal government's potash exploration in Texas and New Mexico, a display of living plants demonstrating the importance of both heredity and environment in molding the organism, a demonstration of the light-sensitive Geiger counter, and a mechanical hen. And there were very many other exhibits equally interesting.

The adequate display of these exhibits was made possible through the courteous and generous action of the City of New Orleans, which provided free of all charge space in the Municipal Auditorium having a rental value of $3,250.

The organizations that furnished these exhibits were: The Department of State; the Treasury Department (Public Health Service); the Navy Department (Naval Research Laboratory); the Department of the Interior (Geological Survey); the Department of Agriculture (Bureau of Entomology, Bureau of Animal Husbandry, Biological Survey, Bureau of Home Economics, Bureau of Chemistry and Soils, U. S. Forest Products Laboratory and Information Office); Department of Commerce (Coast and Geodetic Survey, Bureau of Fisheries, Bureau of Standards and Bureau of Mines); the U. S. Waterways Experiment Station at Vicksburg, Miss.; the Carnegie Institution of Washington (Department of Eugenics, Division of Historical Research, Division of Plant Biology, Moon Committee and Geophysical Laboratory); Tulane University; Louisiana State University; Columbia University; Johns Hopkins University; University of Illinois; Rutgers University; Fordham University; University of Oklahoma; George Washington University; Rice Institute; American Museum of Natural History; New York Museum of Science and Industry; Blodgett Memorial Hospital; New York Botanic Garden; Aeronautical Chamber of Commerce; The Century of Progress (Chicago); Society of American Foresters; Botanical Society of New Orleans; New Orleans Chapter of the Nature Study Society; Science Club of the Morris High School, the Bronx, New York; Society of Petroleum Geologists; Association of Edison Illuminating Companies; Thomas Alva Edison Memorial Exhibit; E. I. du Pont de Nemours and Company; American Steel and Wire Company; and the Leeds and Northrup Company.

The exhibits collectively afforded a wonderful cross section of the achievements and the mysteries of modern science. A study of the exhibits furnished of itself alone a liberal education in the fundamentals of modern science.

It was estimated by those in charge that about 18,000 visited the exhibition hall, demonstrating in the most effective manner that the exhibits were appreciated by the people of New Orleans. In a letter to the exhibitors written after the meeting Dr. D. S. Elliott, the chairman of the local committee, said: "We of New Orleans and Tulane feel that you have helped to sensitize our community to the achievements and potentialities of science, and it is our opinion that you have rendered a splendid service to science . . ."

Quite as interesting and diversified as the non-commercial exhibit was the commercial exhibit assembled by Colonel H. S. Kimberly and displayed in the Venetian Room of the Roosevelt Hotel. Sixteen firms, including dealers in all types of laboratory and class-room equipment, books, filing cabinets and biological supplies and specimens, cooperated in this exhibit. Much of the laboratory equipment shown was new, and a number of appliances were here demonstrated for the first time.

The exhibits serve a most useful purpose in illustrating in a broad and general manner the association's program. As we look back on former years it is difficult to understand how we ever got along without them.

The program is one thing, the local background quite another. Most important is the setting by means of which the meeting, of which the nucleus is the program, is made to harmonize with the background.

Nothing is self-accomplished. A harmonious meeting is the tangible result of well-directed, unremitting, more or less thankless work.

The association appreciates most keenly the unusually efficient and effective manner in which the local committee carried out its work, and tenders them its sincere and cordial thanks for a most unusual and successful meeting.

Austin H. Clark

ROBERT DeCOURCY WARD

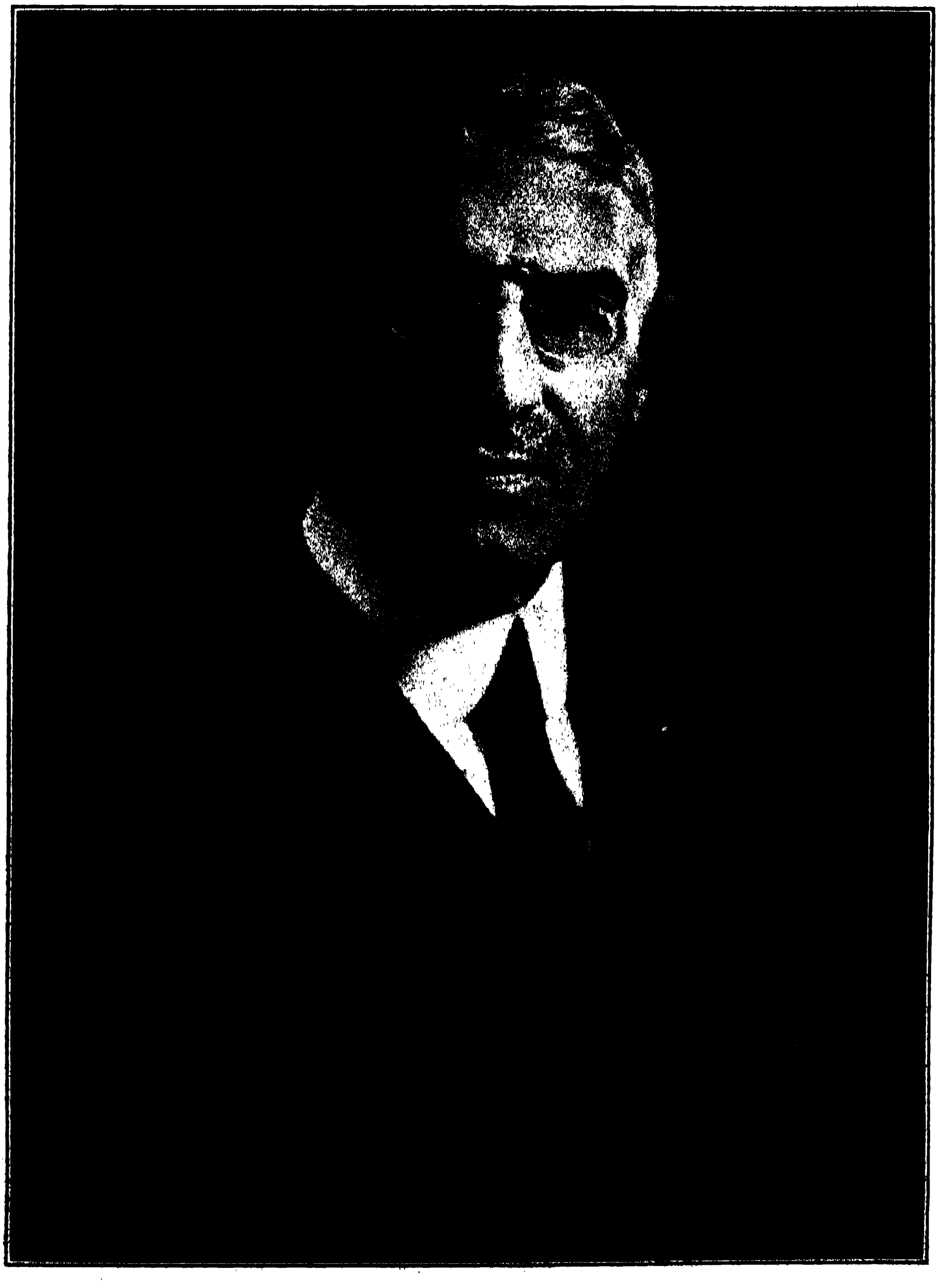
Robert DeCourcy Ward was born in Boston on the 29th of November, 1867, and died in Cambridge on the 12th of November, 1931. He was the son of Henry Veazey and Anna Saltonstall (Merrill) Ward. Henry Ward, the father, spent much of his business life in Valparaiso, Chili, with the firm of commission merchants, Frederick Huth and Company of London. On retiring he came to live in Boston, then was appointed consul from Chili at the court of Saxony. For this reason Robert was taken to Dresden when six months old, remained there four years, then a year in Lausanne, where his father died, a year in England and returned to Boston in 1874. He attended Boston schools, preparing for Harvard at Noble's School. Entering college he graduated in 1889, *summa cum laude*. In his junior year he became interested in studies of the atmosphere through courses taken with Professor Wm. M. Davis.

After graduating he spent a year in Europe, and returning in the autumn of 1890, became an assistant in geography and meteorology at Harvard. Later he became instructor, assistant professor and in 1910 professor of climatology. He was the first one to hold such a chair in America.

In 1897 he married Miss Emma Lane, of Saint Louis, who, with two sons and two daughters, also two sisters, survive him.

Ward had an intense interest in teaching and as a pioneer in his field did an immense amount to bring together and assimilate the knowledge of his subject and put it in form for class instruction. Constantly revising his lectures and laboratory work he ever strove to give his students the essential principles of the subject and the fullest and latest information possible.

He was a great believer in field work, and to gather first-hand knowledge of his subject traveled extensively. He



ROBERT DeCOURCY WARD

LATE PROFESSOR OF CLIMATOLOGY IN HARVARD UNIVERSITY.

was fond of the sea and in his younger days made many trips to Europe; he went to South America three times, visited the West Indies, traveled in this country, and in 1929 went around the world.

Besides his teaching, which he kept up with most painstaking care, both in Harvard College and in Radcliffe, he did an immense amount of administrative work. He was on the administrative board of Harvard College for over thirty years, chairman of the board of freshman advisers for many years, also for several years chairman of the department of geology and geography. In addition he was at times a member of other faculty committees. Too much to require of a man, but he liked the work and did it with painstaking care and good judgment.

Outside of his active professional career he was deeply interested in safeguarding the country from unlimited immigration. From the early nineties he instituted and kept up by writing and interviewing an active effort to awaken and educate the American public on this important matter in which he became a recognized authority. With the late Prescott F. Hall, in 1894, he founded the Immigration Restriction League, the first organization of its kind in America. For over thirty years he was a member of the executive committee, part of the time chairman or president of the league. This interest his son Henry is carrying on.

Besides his teaching, administrative and immigration work he did a large amount of writing. He published "Practical Exercises in Elementary Meteorology," 1899; "Climate Considered Especially in Relation to Man," 1908, with a second edition, 1918; "The Climate of the United States," 1925; "Handbook of Climatology," 1903, a translation of the first volume of Hann's "Handbuch der Klimatologie." Besides these, which are accepted as standard books to-day, he published over 300 longer or shorter papers, and in addition numerous notes or reviews on topics connected with his work. His writing was always clear and concise, and is a remarkable proof of his diligence and ability. Everything that he did he did well and his publications are accepted by men competent to judge as those of a master in his subject. Readers of THE SCIENTIFIC MONTHLY will appreciate the great value of the numerous articles contributed by him to the magazine.

The death of Robert DeCourcy Ward takes a man eminent in his chosen profession and of exceptional nobility of character. Painstaking, careful, accurate in his work, whether teaching, writing or administrative, there was nothing loose or careless in his attitude. He was always to the point. Of a sensitive, nervous, highstrung temperament, he so planned his time that he accomplished an extraordinary amount of work. Liberally generous with others, he was exacting with himself and unsparing in devoted service to the university and to public affairs, in which he took so keen an interest.

He was always interested in the practical application of his subject, climatology, to human affairs. A cultivated gentleman, with a gentleman's point of view, simple, unassuming, he was an example of what is best in a university man. As Dean Briggs said to me, "There was nothing finer than Ward anywhere." His going will make a great gap and many a sad heart.

It was my privilege to know Ward intimately, having been in his department at Harvard for many years, and also for years his next-door neighbor in Cambridge. His loyalty and devotion to his friends was an essential part of his life. His sense of what is right was of the highest order, and I have known him to do things very hard to do because of his keen sense of rectitude. His fine, upright character, his loyalty and his sense of justice were an influence on all about him and will be an inspiring and beautiful memory to his friends.

ROBERT TRACY JACKSON

THE SCIENTIFIC MONTHLY

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WHY WAVE MECHANICS?

By Professor F. M. DENTON
THE UNIVERSITY OF NEW MEXICO

PROLOGUE

WHY physics? If man's object is happiness, he must justify his invention of physical science by showing that it has promoted happiness. Aristotle's ideas of physics (385 to 322 B. C.) were primitive. Was life a less happy adventure for him than it is for us?

Physical science has improved man's methods of travel, of lighting, of heating, of communication, yet with every improvement have come new duties and new forms of unhappy routine.

And how small have been the improvements! The speed given to locomotion has but shortened the hours spent in reflection and drawn out those given over to dull routine. One of the delights of the few rich men who love culture is to travel by coach behind horses.

Means of lighting and heating have been improved, yet the ideal drawing-room of to-day is lighted by candles and heated by flaming logs.

Electricity has brought miraculous means of communication, yet the woman of culture writes with a quill on hand-made paper.

Life is but little longer; health is but little better; sanity has not grown nor the love of beauty.

The love of thought is no greater. The great man is no more capable of thought nor the average man less incapable to-day than thousands of years ago.

Physics is practically useful, its social object being the prediction of future events in the physical world. The sciences of physics and of history combine in performing for society the function which memory performs for the individual; they give of the past a record so orderly that its intelligent inspection discloses the future.

Science has developed the craft of living but has done little to promote the art of life. Always the art of life belongs to the individual rather than to the group.

The pursuit of happiness is often vain, but of this man may be sure, that the well-ordered exercise of his faculties brings happiness. A high faculty is thought, and it is thrice blessed—it blesses highly him who uses it in logic, in reflection, or (mostly highly) in creation.

Physical science offers unlimited scope for the exercise of thought in those three blessed ways, but it is only the rare and gifted man who loves their exercise. It is by holding out this reward of happiness to her followers that science has drawn the world's most thought-gifted men after her and has so wonderfully thriven.

With all its efforts to sugar-coat the pill of learning, education has neglected the attractions there are in thought. Those attractions appear in a study of works of thought in their original forms. Euclid is an exercise in logical thought far more stimulating than any modern introduction to geometry. The modern books may be less faulty in method, but they are dry bones.

Mechanics is made fascinating by Galileo in his book "Two Discourses," to which reference will be made later. Written as it is in the form of a wordy warfare it arouses the fighting spirit in a student and puts a vigor into his logical thinking which the ordinary blase text fails to excite even in the most contentious mind.

Creative thought is neglected in education still more seriously. It is the element of creation in it which gives attraction to invention. The child who loves toys becomes the man who loves invention. The word "toy" has the same root as "zeug" in the German words "Werkzeug," a tool, and "erzeugen," to create.

Every man takes childlike delight in the device or the idea which he feels is his own creation. The pleasure of using such a thing outweighs a hundred inconveniences in its use. A typical example is that of the unknown inventor whose original idea is conveyed in the lines "I eat my peas with honey, I've done so all my life, it makes the peas taste funny, but it keeps them on the knife." The joy of indulging the child of his own thought outweighed indigestion and breach of etiquette. The method used by this inventor was closely related to Millikan's method of holding electrons on oil drops—an invention justly reckoned a stroke of genius.

The joys of reflective thought come to the poet and the philosopher and there is, to-day, no good scientist who is not a philosopher. Students wade through the finished creations of the poets, only the gifted few keeping awake. All would keep awake if they could be shown the daily lives of the poets as they wrote; could see the ragged shirt-cuffs bearing original versions, and could hear from the poet himself all the struggles by which the later versions were evolved.

Thus it is because of the art there is in science that science is good. The essence of art is creation. The tools of the thought-artist are words and symbols. It is because he is an artist that the good man of science cares rather for the ideas behind phenomena than for phenomena.

Training and education are powerless to produce either men of art or men of science, and there is as little hope that, some day, all men will understand Einstein as that all men will understand Bach.

And if, as seems likely, the theory of relativity will remain forever mysterious to the majority of men, much more will those theories remain mysterious which are growing out of relativity. The youngest of these are the unified field theory and wave mechanics. So peculiarly difficult are these theories that the task has become a very interesting one of enquiring what they are and why they have been invented.

MONOLOGUE

This paper is intended as a discussion of scientific method, based on a brief review of the outstanding theories of physical science since the time of Newton (1642–1727). The first of these theories is Newtonian mechanics. In order to bring electrical phenomena into the scheme of Newtonian mechanics, Clerk Maxwell (1831 to 1879) invented the electromagnetic theory, by which light became an electromagnetic phenomenon. The velocity of light is a quantity of fundamental importance in every branch of physics. In Clerk Maxwell's theory it is constant; in Newton's it ought to be variable. The difficulty was winked at until 1905, when Einstein invented his theory of relativity. That theory reconciled the behavior of light with that of moving things in general, but it found no place for other electrical phenomena.

Einstein's unified field theory is an endeavor to bring all phenomena, whether electrical or mechanical, into the generalized theory of relativity.

During the growth of relativity (1905 to 1915) a new complication was coming into experimental physics and, again, light was the culprit. It was behaving in a large class of phenomena rather like bullets than like waves. Matters were but poorly patched up by Planck's Quantum Theory (1900).

Physicists began to follow two lines of theory involving notions about light and radiation which were mutually contradictory. Out of the struggle have come the group of theories known as wave mechanics, in which the distinction between bullets and waves is held to be unwarranted and misleading. The pioneers in wave mechanics are Heisinger, de Broglie and Schroedinger.

In order to make the meanings and relations of the theories of physical science intelligible, it is necessary to describe them in one continuous line of thought. Intelligent reasoning demands continuity. We reason by thoughts and thoughts grow out of memory. Reasoning is without meaning if its "thread" is lost. A long break in memory is called amnesia, and amnesia is a form of insanity.

Complete knowledge would provide a continuous picture of the consequences of a given set of conditions. Consequences must be consecutive; events must form a sequence, and a sequence must be definite and unambiguous. A break in a line of reasoning is a point at which doubt creeps in.

The dogmas just recited form part of the practical creed of most men, and confusion is unavoidable unless they are respected.

Aristotle's knowledge of physics was so limited, so full of breaks, that it was impossible for him to form a clear picture of any complex sequence of physical events without the help of fancy. If, for instance, he had tried to picture a big and a little man throwing themselves simultaneously from the top of a tower, he would either have been in doubt as to which man would strike earth first, or, if he had relied on his own peculiar notions, he would have concluded that the big man would reach earth so much earlier than the little one that the latter might use his big brother as a cushion to fall on. Galileo (1564 to 1642) discusses such problems with clear insight in his "*Discorsi e dimostrazioni matematiche intorno a due nuoue scienze attenenti alla mecanica e i movimenti locali,*" printed at Leyden in 1638, an English translation of which was published by Macmillan in 1914. He makes clear, without special experiment, the error of Aristotle's notion who held that "an iron ball of one hundred pounds falling from a height of one hundred cubits reaches the ground before a one pound ball has fallen a single cubit." Aristotle was an artist as well as a philosopher. Neither art nor science can suffer discontinuities. When blanks are found they must be filled—in art by fancy, in science by creation. Aristotle used fancy.

The theories created by Newton and Galileo removed doubts from men's picture of falling bodies. Nevertheless Newton's knowledge of physics was so limited that he was unable to form a clear picture of a complex sequence of events in the field of optics. He was in doubt as to the speed with which the light from the rising sun traversed the earth, and if he called light's speed with reference to the sun V miles per second, while the circumferential speed of earth was v, Newton simply did not know whether the speed of the sun's ray across earth was V or (V + v) or (V – v). His picture of light's behavior either had to have blank spaces in it or had to be filled by guesswork.

Einstein's theory has removed the guesswork from the problem of the speed of light and has improved the logical sequence of the sciences of mechanics and optics, but it has left science faced with new forms of discontinuity. Is a beam of light a wave in a continuum, or is it a hail of bullets?

The fight with this problem has brought new difficulties as well as new knowledge. Light has undoubtedly the property of bullets as well as that of waves. In trying to remove the absurdity from such a contradictory mixture of properties scientists have discovered a contradiction still more absurd. Bullets—the electrons we have always pictured clean and round like billiard balls—are waves. Nothing could be more absurd, yet nothing is more certainly a "fact." Davisson, Germer and others (1923 to 1927) have shown that just as a narrow beam of light may show diffraction bands of light and dark on a screen—the light energy crowding along certain preferred directions—so also will a narrow beam of electrons, after reflection from a metal surface, crowd along certain preferred directions.

The mind has no sort of picture to fit such queer events, and the picture which science offers to-day of the world of nature is full of blank spaces. How to fill those spaces by guesswork has been shown, very plausibly, by Heisenberg. How to fill them by "material waves" is suggested by de Broglie and by Schroedinger. The weakness in the method of "material waves" is that it leaves discontinuities in the relations between electrons. There is no visible way out. So great is the difficulty that scientists are to-day testing themselves to see whether while still remaining comparatively sane, they can accept the notion that reality involves discontinuity.

The difficulty of accepting discontinuity is seen by reading thoughtfully one of its fundamental consequences, namely, the notorious "Principle of Indeterminacy," which runs, "An electron can not have, simultaneously, both position and velocity." The absurdity of this is so great that words can hardly convey it. If we know anything at all about electrons we know they are usually in motion. Thus we know they exist in time. According to the new principle they can not also exist in space. Zeno would have enjoyed the situation; and, after all, it may be doubted whether we have in the world to-day any thinker greater than Zeno.

In the hope of making the development of modern science intelligible, it is useful to consider from a practical, unimaginative point of view some of the phenomena which have seemed to demand the theories.

The poets' notion that the starry heavens were a crystal bowl studded with bright jewels took no account of the fact that the sun was earth's powerhouse and the moon the engine of the tides. These facts and the observations of the astronomers demanded Newton's law of gravitation. The line of reasoning was simple. The simplicity and regularity of their relative motion led to the tentative assumption that sun and earth were interacting mutually, according to some physical law. There appeared to be some force between them. Symmetry and common-sense demanded that this force should depend only on the amount of matter in the bodies and their distance apart. Something analogous to elastic strings—"lines of force"—was demanded, joining earth to sun. Simplicity would be served if one common law could be found which might be obeyed both by bodies on earth and by stars. Every-day experience of the fact that the weight of a body was unaffected by the intervention of other bodies between it and earth demanded that the lines of force should be continuous strings, not capable of being broken or cut. Symmetry demanded that the lines of force sent out by the sun should be straight radial lines whose density must fall off with the square of the distance from the sun's center. Hence came the inverse square law of gravitation. Such a law would account, mathematically, for the relative motions of sun and planets as well as of falling bodies on earth, provided it were assumed that, in the absence of such forces, those bodies (stars and stones) would move in what an earth-dweller called straight lines. The fact that the paths an earth-dweller would call "straight" would not be called straight by a Martian or a sun-dweller was not seen as an objection because people had not yet appreciated the "other fellow" condition in the scientific definition of "truth." Strictly, Newton's laws of motion are not laws of nature. They are mathematical deductions from the assumption that, in the absence of "forces," bodies would move in "straight" lines—an assumption which is scientifically meaningless, because "straight" is unavoidably ambiguous.

The attribution of the uniformly accelerated motion of falling bodies to the "force" of gravity combined with the common-sense demand that the "amount of matter" in a given body should be conserved led to Newton's definition of "force" by the equation $F = MA$.

The Newtonian law of relative velocity needed no experiment, but was "of necessity" true, if the Newtonian-Euclidean picture of the world was true. A man walking forward at 5 miles per hour along the deck of a ship travelling 10 miles per hour was, "of necessity" moving, relatively to earth, at 15 miles per hour. The reasoning was applicable to anything whatever, conveyed by any vehicle whatever. For instance, it should be applicable to a ray of light travelling on a stream of water through a pipe. Fizeau (in 1856) found that in this case Newton's law was wrong. The arithmetic sum of the velocity of light in water and the velocity of the water in its pipe proved actually to be greater than the velocity of the light carried by the water along the pipe. This "absurd" behavior of light was found to be in accord with the "dragging coefficient" which was invented in 1816 by Fresnel to account for some of the facts of aberration. That coefficient is closely related to the "Lorentz Transformation" of Einstein's relativity.

Light's behavior was excused but not explained by Fresnel's dragging coefficient, that coefficient being a brilliant guess, not a scientific deduction. For many years light's unorthodox behavior was winked at and in 1887 the Michelson-Morley experiment proved that the culprit was unrepentant. In 1905 Einstein proposed that since light was more powerful than science it might be well for science to capitulate, annulling its "classical" laws and inventing new ones to fit the "absurd" behavior of light. Einstein's success was a wonderful triumph for the scientific method. Instead of having to annul the old laws Einstein found that it was necessary only to complete them. For instance Einstein's law of relative velocity is $V = (v_1 - v_2)/(1 - v_1 v_2/c^2)$ where c is the velocity of light. For the special cases (and these happen to be all ordinary cases) in which the velocities are small compared with light's velocity Einstein's law is indistinguishable from Newton's.

Newton's assumption that the mass of a body is conserved remains true for bodies at rest or moving with any ordinary velocity, but the strict law, as formulated by Einstein, is $M = M_0/\sqrt{(1 - v^2/c^2)}$ in which M_0 is the ordinary Newtonian value of the mass and v is the body's velocity relatively to the observer.

Light and all known forms of radiation, as well as bullets, falling bodies, planets and stars—all things obey these laws of Einstein better than they obey the laws of Newton.

By Einstein's theory the law of inverse squares for gravitation is not quite right. The exponent should not be 2, it should be 2.00000016. In a Newtonian-Euclidean world this not only is wrong, it is absurd. The geometry of Euclidean space demands the exponent 2. The density of the lines of force of a symmetrical radial field of gravitation must fall off as the square of the distance. Einstein has shown that the geometry of the physical world is non-Euclidean.

The big-scale events which have corroborated Einstein are well known, as, for instance, the bending of light in the sun's gravitational field. Among the small-scale but accurately observable events are the change of a body's mass with its velocity and the transformation of mass into energy. The transformation of mass into energy is thought to be demonstrated by the fact that the atomic weight of helium is exactly four, whereas its structure demands a weight of 4.032. The deficiency is explained as due to the energy given off during the formation of the gas from electrons and protons.

The fact that energy possesses mass is demonstrated by the well-known phenomenon of the "pressure of light." Anything which resists change in its motion has inertia, and inertia is mass. When light falls upon an opaque body it is stopped or deflected. Does it push against the body? If so it has mass. Lebedew showed in 1901 that light does push upon a mirror. In order that it might be moved appreciably by a minute blow the mass of the mirror had to be small; in order that the force of the blow might be as great as possible the mirror's surface ought to be large. For a given shape of mirror the ratio of surface to volume is a maximum for the smallest possible mirror. Lebedew used mirrors a fifth of an inch in diameter, suspended in a vacuum. He found that ordinary sunlight exerts a pressure of about a milligram on every square meter of an opaque surface. In proper accord with the notion that light has mass this pressure was found equal to the energy-density of the light.

The many corroborations of Einstein's theory which modern advances in physics have brought give great encouragement to the notion that the physical world is a world of continuity. This can not, however, reduce the seriousness of the ruffling which Planck's quantum theory has brought into the space-time continuum. Some of the facts demanding Planck's theory are simple, as, for instance, the photoelectric effect.

When light strikes the surface of a metal that surface emits negative electrons. This is true especially of the alkali metals, such as sodium. But the removal of these electrons requires energy. The energy required may be measured by finding the voltage to which the metal must be charged to produce a leakage of current. Einstein and others have found precise values for the number of ergs required to remove one electron from a given metal with a given velocity.

Common-sense would suppose, therefore, that the action of light would cause the emission of electrons only if its intensity were great enough. The ergs of light energy per square centimeter of the metallic surface ought to equal the energy of the emitted electrons (allowance having been made for what may be called the "surface tension" of the metal).

Experiment shows that no such intensity is required. The energy with which an electron leaves the light-excited surface depends on the frequency and not at all upon the intensity of the light. It is as though the electrons had the intelligence of schoolboys who, when the clock strikes eight, go forth with low energy, but when it strikes twelve, shoot forth with high energy. This odd analogy may be carried a step further. The intensity of the light, of whatever frequency, determines the number of electrons leaving the plate per second; similarly, the loudness of the bell, whether it strike eight or twelve, determines how many boys will awake and go forth. Unfortunately, the rules of the game of science forbid the assignment of intelligence to electrons, and it is necessary to seek an explanation more prosaic.

The favored explanation is the quantum theory, according to which the old idea that the radiation from a point source is propagated after the manner of a rubber balloon expanding outwards from its center, its radius growing with the speed of light, must be replaced by some such picture as that of an expanding spherical cloud of bees. The wave-front is not like a uniform spherical shell of rubber, but is rather like currants peppered over the surface of a spherical pudding, each currant containing enough energy to eject one electron from the surface of a metal target. This crude picture must next be complicated by the notion that what each bee or currant carries is a quantum not of energy but of "action"—action being the product of energy and time. This makes the picture satisfy the condition that the energy of emission of each electron shall be proportional to the frequency of the radiation represented by the cloud of light quanta. The unit of "action" carried by each quantum—of whatever frequency—is Planck's constant, "h," which equals 6.55×10^{-27} erg-seconds. The product of action and frequency (that is to say erg-seconds and a number per second) is energy. A quantum of radiation of frequency ν carries energy $h\nu$, and it is this amount of energy that an electron possesses when it is emitted from a surface.

Such a picture of radiation as discontinuous has fatal objections; for instance, at a great distance from the source of the radiation the bullets (bees, currants or quanta) are scattered so sparsely over the wave front that the chances of any given spot on the target ever being hit are small. Hence the emission of electrons from the target should be patchy, and it should happen sometimes that considerable time would elapse between the arrival of the geometrical spherical surface, usually called the wave-front, and the ejection of an electron from a given spot on the target. The ejection is in fact practically simultaneous, at all points on the target, with the arrival of the geometrical wave-front.

The quantum idea is plausible, but it provides the mind with no logical picture. The very idea of discontinuity is unreasonable (or beyond reason) because the tool reason must use is memory, and memory with breaks can produce nothing better than a broken line of reasoning patched with guesswork.

The simple atomic picture used by the chemist is atomic only in a superficial sense; the "reality" of the chemical atoms lies in their chemical affinities, and we picture these affinities as the evidence of fields of force—for it is only through their fields that the atoms of different elements can be recognized and distinguished. A field of force has no fine-drawn boundaries; the gravitational field, for instance, of a particle extending through unbounded space. Similarly, the electron, though pictured crudely as a little billiard ball, has to be dealt with scientifically as a radial electric field extending throughout all space.

There is no more objection to the idea of discontinuous quanta than to that of atoms and electrons, but there is as much objection.

Wave mechanics tries to treat quanta as electrons have been treated, namely, to bring them into a field theory. The point of view from which the problem is being attacked is that of atomic structure. Bohr's (1913) notion of an atom as a planetary system provided the mind with a clear picture, but that picture involved mysterious discontinuities. Around the atom's center moved electrons in definite orbits. It was the dogmatic definiteness of those permitted orbits that reason could not suffer. What happened in the empty space between the orbits? Radiation was given out from an atom by the apparently miraculous jumps which electrons sometimes made from one permitted orbit to another. Where was the electron during the jump and what was happening to it? There was no intelligible answer. The principle of indeterminancy says it was "nowhere."

Bohr's planetary picture is wrong. What made it plausible? No microscope can look into an atom. This is stated dogmatically because, by sound principles of optics, in order that two points may be recognizable under a lens as distinct their distance apart must be at least λ/a centimeters; λ being the wave-length in centimeters of the light being used, and a the angle in radians subtended by the lens at either of the two points. This means, for instance, that if ordinary light were used, for which λ is about 6×10^{-5} cms, and we could put the object close to the lens, making a about 3; the size of an atom whose diameter might be clearly visible must exceed $(6 \times 10^{-5}/3) = 2 \times 10^{-5}$ cms. The probable diameter of an atom of helium is 2×10^{-8} cms—a distance one thousand times too small to be distinguished microscopically. As to the electron, it is supposed to have a diameter one fifty-thousandth of that of an atom.

The planetary atom of Bohr is an inference from many big-scale measurements; especially from spectroscopic data.

A gas which is heated, or through which an electron discharge passes, becomes excited, the motion of the electrons within the atoms becoming sufficiently vigorous to set up visible vibrations in the ether. (This seems to contradict the notion that matter moves through the ether without disturbing it. The ether idea is, however, at best an artificial makeshift, and we can suppose that although the ether offers no resistance to the motion of big things through it, it does resist the motion of electrons and take up energy from them). A narrow ribbon of such light forms a spectrum containing components of many colors, that is to say of many different frequencies. The simplest notion is that if the strip of light, after dispersion by a prism, forms, say, three separate images of different colors, there must be three electrons rotating at different speeds, and therefore in orbits of different radii, around the nuclei of the atoms.

The reasonableness of such a notion is tested by spectroscopic observations supplemented by alpha particle experiments, such as those of Geiger and Royds, from which the amount of positive charge on the nuclei can be inferred —and hence the number of electrons since the atom complete is neutral—and by experiments in which the atoms forming a gas are subjected to electronic bombardment.

The results of experiments such as have been outlined have led to many ingenious pictures of atomic structure, each of which is plausible, but all of which fail in important ways to fit experimental fact. The chief discrepancy is between the values obtained spectroscopically—especially by aid of the x-ray spectroscope of Moseley—for the numbers of the electrons within the atoms and their frequencies, and the values deduced from bombardment experiments. The frequency of the emitted light differs from the speed of rotation of any of the planetary electrons whose presence is disclosed by bombardment.

This difficulty, added to the impossibility of picturing the discontinuity introduced by the supposed orbit jumps, has called for some new mode of explanation and has produced wave mechanics.

Distinction must be drawn between the three forms of wave mechanics associated respectively with the names of Heisinger, de Broglie and Schroedinger. Heisinger, whose ideas are favored by Bohr, assumes that, however repugnant it may be to common sense, we must accept the fact of discontinuity. De Broglie and Schroedinger try to fill the world-continuum with waves. Except for this difference in intention, the three forms of the theory seem to be in fair agreement.

Discontinuity means ignorance or uncertainty. In the presence of uncertainty we have to make guesses, and in order to make good guesses we must use the mathematical theory of probability. Thus in Heisinger's theory Planck's constant "h" becomes a measure of "inaccuracy." This point of view may be explained in a common-sense way by reference to the problem of finding the position and the velocity of a given electron within an atom at a given instant. To do this by actual observation is impossible by means of any known microscope, but we will neglect the mere practical difficulties and suppose the very short-wave light of gamma rays (the wave-length of which is a hundred-thousandth of that of ordinary light) to be used in an imagined gamma-ray microscope.

As is well known the error in determining the position of a point by means of a microscope is λ/a, λ being the wave-length of the light in centimeters and a the number of radians subtended, at the object, by the lens aperture. Thus, for instance, if λ were one thousandth of a millimeter, the lens aperture were half a centimeter and the focal length two centimeters, the value of λ/a would be about one twenty-five-hundredth of a centimeter and the location of a point on the object (defined, say, as its distance from the center of the object) would have an uncertainty of (1/2,500) centimeter.

The electron's velocity may be found from its momentum, since the mass of the electron is known. The experiments of A. H. Compton (1923) on the scattering of x-rays by particles of graphite have shown that the ray of light thrown upon the electron while its position is being measured, must possess momentum equal to $h\nu/c$, h being 6.55×10^{-27} erg-second, ν the frequency of the light, and c light's velocity.

It is possible that the whole of this momentum may be added to that of the electron whose momentum is being measured, the error in momentum then being $h\nu/c$, which may be written h/λ since $\nu = c/\lambda$. How much of this momentum will be given actually to the electron depends on the direction of the light falling upon the electron, and all we know about that direction is that it lies within the aperture angle a. The probable error p_e in momentum is thus h/λ times a.

The probable error q_e in position was λ/a, and we have the interesting result, $p_e \times q_e = h$.

The quantity $p_e q_e$, the product of distance and momentum, is of the nature of "action"—since energy times time equals distance times momentum. The statement $p_e q_e = h$ thus means that in measurements of action—the most fundamental stuff in the physical world—there must always be a probable error of the magnitude h ($= 6.55 \times 10^{-27}$ erg-seconds).

Such an error is negligible in big events but becomes the "whole thing" in the ultra-microscopic events that go on inside an atom.

The notion of "action" is unfamiliar, but if we accept the conclusion of relativity that energy and matter are one, then action may be thought of as matter times time, as, for instance, a brick times a second. There is nothing unfamiliar about that idea. A brick is an abstraction, for a brick needs time in which to have its being. A "brick-second" is a physical reality, it is a lump of "action."

The derivation which has just been given, of the equation $p_e q_e = h$, can not be taken to suggest that the error h might be avoided if a more perfect microscope were used, because λ and a cancel. The blame must be put upon h and not upon the method of measurement.

If the orthodox position be taken that nothing is real which can not conceivably be measured, then, since no method can be conceived by which the simultaneous position and velocity of an electron can be measured accurately, we must conclude that the notion that an electron can possess, simultaneously, both position and velocity, is wrong and probably meaningless. This is the position taken, officially, in Heisinger's theory, according to which science must be illustrated not by pictures but solely by mathematical equations.

De Broglie and Schroedinger seek to explain apparent discontinuities in terms of the interference of waves in continuous media. Any diffraction pattern with its bands of light and darkness may be called a discontinuous patch of light, but the conventional ether-wave explanation calls for nothing atomic or discontinuous. Thus effects apparently discontinuous may be consistent with a theory of continuity.

These continuity theories of wave mechanics are successful up to a point, but they reach then the same position and the same difficulty with which de Broglie's theory starts, namely, the necessity of assuming that the physical world is not picturable as a continuum. The inference is that there is an absolute characteristic in nature which shows itself as an "uncertainty."

Science thus becomes an application of statistical methods and the law of probabilities is seen as nature's fundamental law.

To conclude from this, however, that the physical world is a random shuffling of quanta of action is unwarranted and foolish. The fact that statistical methods give true predictions and useful results shows that the discontinuities are directed.

If I toss a penny it shows either head or tail, never a head and a half or a tail and a half. It is a matter of chance whether head or tail turns up. Nevertheless, in a hundred throws it is practically certain there will be fifty heads. In each throw there is the same amount of error, namely, one quantum of error. An error is something done without intention. It may be called "undetermined." From a hundred throws we deduce the thrower's intention, which was (if he had a sane orderly intention at all) to make the penny stand on its edge. Every step in the process is an error, yet the meaning of the process is definite.

Another familiar example is that of human handwriting. If the writing is, as usual, irregular and broken, then every little elemental stroke is inaccurate. If it be called on that account "undetermined," we may say, "although the elementary processes of the writing are in no way determined, yet the probabilities to be ascribed on statistical grounds to these individual processes may be treated as continuously variable and determined quantities." Such is the form of words used by some modern authorities in speaking of the processes of physical science. It may be questioned whether such words are warranted. Is it not misleading to say the individual processes may be "undetermined"?

In a game of chance—as, for instance, the tossing of a penny—the endeavor is to choose individual processes (the throws) which are "undetermined" as to their sign. This does not mean that the sign (head or tail) of each throw is uncaused; it means rather that the sign is determined by causes having no systematic relation to the game. We are accustomed to thinking that in such an actual case there must, strictly, be some distant relation between all the events, but that the relation of the forces deflecting the penny, to the throwing of the penny, is so distant as to be negligible. Yet surely, if we could do so we should make the sign of the throws obey causes absolutely unrelated to the game. Then the sign might be called "undetermined." But to use the word "undetermined" is misleading, because, though the sign of each throw is undetermined, there is something about each throw which is determined; and it is that something which comes to light in a long series of throws. Inspection of a long series discloses "indifference to sign." This is the characteristic of the game. Similarly in the handwriting. Inspection of a whole sentence—each element of which is inaccurate—disclosed definite meaning. The inaccuracy present in each stroke is undetermined, but in each stroke there is present something besides the inaccuracy.

If each stroke were characterized by nothing but inaccuracy then the statistical method (which, through practice, the eye always applies to handwriting and to pictures) could disclose no meaning in the writing. It is a general tendency present in each stroke which is the element of truth. Without that tendency the statistical method would disclose nothing. Statistical methods can disclose truth by canceling the errors which hide it, but they can not create truth. It is absurd to suppose that out of nothing but undetermined elementary processes determined results may grow. The elementary processes must have some determined characteristic giving them a relation, so that out of that relation the determined event may grow.

It is vain to attempt to abstract a physical conception from any of the wave mechanics theories in their present form. Perhaps no physical conception of nature's elementary processes is possible. A physical conception is a conception in terms of familiar notions. Both relativity and wave mechanics concern notions which are unfamiliar. Not until those notions have become familiar can a satisfactory physical conception be recognized for either theory. But to forego the enjoyment of a physical conception is much easier than to accept as final a theory of discontinuities. Such a thing is acceptable as a temporary makeshift but not as final.

The makeshift conception that Aristotle had to tolerate was that of a multitude of separate worlds, each with its own "god." Scientific events were not distinguished from spiritual events. There was no world of science; no language of science; no logic of science. It is striking that a thinker of Aristotle's power could be such a child in scientific reasoning as to favor the idea that a heavy body—because it is heavy—must fall more rapidly than a light one. In scientific thinking Galileo was far ahead of Aristotle. Here is the brief substance of Galileo's argument about falling bodies:[1]

Aristotle claims that a light bullet falls less rapidly than a heavy one. Suppose then that the heavy bullet be lying just on top of the light one as they fall. The light one must retard the heavy one, and the combined pair must move a little more slowly than the heavy one would if falling alone. But the combined pair, being a heavier thing than the heavy bullet alone, ought to fall, according to Aristotle, faster. Such contradiction shows Aristotle's theory to be absurd.

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[1] See Galileo's "Dialogues Concerning Two New Sciences" already referred to, p. 64.

Newton's world, in the improved form in which he left it, was hampered by the discontinuity separating time and space. In introductions to relativity that peculiarity of the Newtonian world is made clear. An observer sees the path along which he himself happens to be moving as a combination of space and time—every mile of travel involving some minutes of time. Only the path perpendicular to his own—the path along which his own motion has no component—is pure space; and this path, to a differently directed traveler, is a mixture of space and time. Relativity removed that discontinuity. The discontinuity which, in its turn, disturbs relativity is a very fundamental one; perhaps it is the very same which, in different guise, plagues wave mechanics.

A fundamental assumption made by Einstein in his "Special and General Theories" was this, that rods and clocks were true standards in the sense that if they were found in mutual agreement at the outset when all were together, at rest in one spot, then, in spite of contractions and slowing due to motion and to gravitational fields as they went on their various journeyings, they would be found still in agreement on coming together again for restful comparison.

The difficulty is brought out by the case of the "identical twins." It follows from the general theory of relativity that if there are two identical twins, A and B, one of whom, A, remains at home while B goes off at high speed for a journey, returning after many years, then, on reunion, A will be a gray-haired old man while B will have remained youthful.

This deduction from relativity is not easy to explain, but light may be thrown on the matter by some simple thoughts. Relativity defines reality or truth as that which is seen similarly by all observers. If then an observer can be specified to whom the men A and B must always appear alike, the contention that A will have aged more than B will have been disproved.

Now if an observer X be specified who chooses to move in such a way that he is always midway between A and B, then, in reference to him (X) the velocities of A and B must be always equal. Hence the contractions seen in A and B and the slowings seen by X in their watches and their beards will be the same for A as for B. And when finally A, B and X are reunited, X will find A and B still "identical."

That argument is incomplete, for it neglects gravitation. A and B were born within earth's gravitational field in which clocks were slowed and rods shortened. As B moved away, possibly into regions of less gravitation, X would find it impossible to choose his own motion so that A and B would look always alike. To be midway between A and B would not suffice, for, in addition to maintaining his velocity relative to A the same as relative to B he would have to accelerate himself in one direction at two rates at once, in order to counteract the two different gravitational fields to which A and B were subjected. Do what he might X would see differences between A and B. Those differences would be "real."

When the "identical twins" are a pair of yardsticks, the conclusion is that those sticks must not be assumed to remain alike. They start out alike, but later, when brought together again, they will be unlike. This difficulty may be regarded as a case of discontinuity. To the observer who lives in the calibrating room to which rods return to be checked, it will appear that the length of a rod is a quantity varying in erratic jumps.

Weyl and Eddington have tried to surmount that difficulty by discarding the idea that the world is capable of an unambiguous metrical description. Instead of equipping each observer with a standard yardstick they send him out with no stick at all, but tell him to use the yardstick he finds on the spot. It does not "really" matter what lengths those local sticks have. According to this theory the physical world is described in terms of relative position and not by quantitative measurement.

The fact that Planck's constant, *h*, has a definite size seems to suggest that, after all, a metrical description must be possible and in his unified field theory Einstein does make possible a metrical description of physical events. The practical interpretation of the theory has not yet been disclosed.

A complete theory must find room for every known phenomenon.

The phenomenon of cosmic rays is new and but little understood. Rays of light possess speed and momentum, and when they hit atoms they sometimes drive out electrons. These loose electrons are ready to be set in motion by electromotive force, hence the space in which they are produced becomes an electrical conductor.

X-rays and the still higher frequency gamma rays make ordinary air conductive; Hess discovered in 1912 that cosmic rays are still more effective. The frequency of the cosmic rays is probably of the order of 5×10^{22}, while that of gamma rays is 5×10^{19}, x-rays 3×10^{19} and of ordinary light 5×10^{14} cycles per second.

Recent work has been done by Millikan and Cameron which shows that cosmic rays have 700 times the penetrative power of x-rays, being able to pass through 30 feet of lead. Cosmic rays fall upon earth from no particular direction; it is thought that they come from interstellar space. Their apparent lack of systematic relation with any other phenomena fits them well for use in games of chance.

The game of penny-tossing is a game of true chance for two reasons; first, a penny is so small that the force required to knock it over when standing on edge is a much smaller force than can be detected and controlled, voluntarily, by a man's muscles. A penny as big as a dinner plate would not do, for, with practice it could be made to fall as desired. Secondly, penny tossing is a game of true chance because the forces determining the sign of the throw—such forces as accidental breezes, vibrations of the thrower's chair or disturbances of his nerves—have but very distant relation with the throwing process. It is because these conditions are satisfied that the game gives, practically always, the result which the mathematical theory of probability demands.

It is not easy to know whether a proposed game is one of true chance, but in cases in which the experimental results do actually agree with the theory of probability the inference is fair that the conditions necessary for chance are being fulfilled.

The results of experiments in atomic physics are predictable by no theories except those which use the mathematics of probabilities; hence the tentative inference is warranted that the conditions of true chance exist inside atoms. As applied to the planetary picture in which the observable effects (line spectra, etc.) are supposed to be due to an "undetermined" jumping of electrons from orbit to orbit, the suggestion seems plausible that the unrelated accidental causes of those erratic jumps are cosmic rays. It is good to have something to blame for one's failure. What could be more convenient for science than to put the blame for its failure to find a reasonable theory of atomic phenomena upon the shoulders of the infant cosmic ray?

EPILOGUE

In a final analysis, the idea of truth or falseness is inapplicable to an individual ultimate element. It is only the relations of such elements that possess significance and may be true or false. Here, for instance, is a sentence, every word of which is without meaning, "Cees tym bi thef orlok," but whose meaning every reader knows. The sentence has a continuity; the words have a relation. Without relation there is no significance; without continuity (actual or inferred) there is no relation.

This peculiar sentence seems to be a case in which the group has a meaning, although each element is without meaning. A more striking case of this sort is that of a message in the dots and dashes of the Morse code. A dot standing alone has no meaning, neither has a dash; but a group has meaning. Here, apparently, is a discontinuous series exhibiting a relation which has meaning. But is the series really discontinuous? If so why does · · · mean S while · · · means EI? This is because the relation involves the spacing as well as the dots, and the series is not really discontinuous. Discontinuity would demand that the spaces between elements should be truly empty—filled with nothing that has significance. Actually the spaces have as much significance as the dots, and the discontinuity is not real. And since an isolated dot has no meaning we ought to say that not the dots and dashes are the elements in the message but rather the elements are dot-plus-space groups. The continuity is then obvious.

Science defines the real as the unambiguously measurable, and since a space enters into the measure relations of the group just as a dot or a dash, it is just as real.

The case of the "forelock" sentence is interesting because it seems like a case in which real significance is conveyed without any measure relations at all, nothing metric being apparent in the relation conveying the significance. But is there really nothing metric in the sentence? Are not the time-spacing of the syllables and their intensity-relation essential to the significance? Without memory's recognition of the sentence no significance would be conveyed; and recognition is a sort of measurement.

The discussion of the problems of atomic science tends to become as confusing as the discussion of religion, if those arbitrary distinctions are lost sight of by which physical science is kept separate from abstract science. And yet to respect those restrictions seems often impossible because on close inspection they are unrecognizable.

Perhaps it is too much to hope that any restrictions at all can be formulated which can claim general recognition. We shall assume, however, that the field of physical science is restricted to those events whose unambiguous description is possible in terms of measurements made by rods and clocks.

In order to insure that a description shall deal with only one event at once we define "event" as something identifiable. And since if a thing has a break in its existence (*i.e.*, goes out of existence for awhile) it loses its identity, we assume that, by definition, discontinuous elements in events are excluded.

From this point of view the principle of indeterminacy is excluded from physical science, or, if tolerated, is regarded only as a temporary makeshift, and its introduction into scientific theories with the status of a "law" can lead only to confusion.

In retort it may be said that if no law can be tolerated which permits discontinuity in scientific processes then physical science is deprived of its only foundation, namely, the law that *an event which has happened before is likely to happen again*. Science fulfils the important function of prediction, by the use of this law, and yet by it the connection between events is one merely of likelihood or chance and the theory of probability becomes the foundation of scientific description. Faith in continuity is lost; we treat physical events as games of chance.

Thus the conclusion seems to be warranted that while the accepted definition of the field of physical science forbids a principle of indeterminacy, the fundamental law on which the scientific method is based does actually involve such a principle.

Now the official apology for the principle of indeterminacy recently introduced into atomic physics is this: Science defines reality as something unambiguously measurable. The velocity of an electron, when in a given position in an atomic orbit, is not measurable, hence there is "really" no such thing, and the principle must be accepted that an electron can not possess simultaneously both position and velocity.

If this be accepted then science becomes a game of chance and scientific theories must be built out of equations in probabilities.

The determinist may reply by showing that no game of true chance is possible and that, therefore, theories based on the principles of chance must be either makeshifts or delusions.

In a game of true chance the signs of successive throws must be undetermined in the sense that their causes have no systematic relation to the game. But if we look closely into the game, as for instance by analyzing two successive throws, we find a completely determined series of events. For instance, the vibration of the thrower's hand gives the penny a tilt as it rises; this tilt determines the number of somersaults and this gives sign to the throw. The succeeding throw starts in a manner determined by its predecessor, and so on. Thus the system or sequence of the causes of the signs of successive throws is disclosed.

The determinist may thus claim that since, on close investigation of the matter, he finds it impossible to conceive of measurements by which effects due to *systematically unrelated causes* can be recognized, there are in nature no such things.

The apparent impasse arises from a confusion. The scientific point of view is that it may be difficult but never can be impossible to find the systematic relation between events. This point of view is confused with the position in which actually we stand of being unable, by our very natures, to predict the future except as a probability. The notion is meaningless that we may experience future events without waiting for them. How we regard this fact is a matter of taste, but it is misleading to interpret it as a proof that the future is "undetermined." The future is unknowable but in all probability it is determined.

This ramble leads nowhere, but it encourages an attitude of unfriendliness towards atoms. The atom is the symbol of discontinuity. However small the atom may be, the mind pictures it with an "insides" which calls for investigation. The reality underlying nature can not be reached by way of the atom. The element of atomicity is burdened asymptotically, like the flea of the poem, and the mere numbering of its sub-elements must go on "ad infinitum," although it may be just as finite and comprehensible as the flea.

There is no warrant for the hope that finality of scientific knowledge of the physical world is attainable, but nothing forbids the hope, and it seems a pity to adopt a system like atomicity, one of whose rules is that finality shall be unattainable.

The alternative to atomicity and discontinuity is the field system. The human mind is not inquisitive about the "insides" of a line of force. A field of corn must have stalks—a sort of texture; a field of force, or a continuum need not. Common sense has no objection to the possession of properties by empty space (radio having made the idea familiar). Neither space nor time demand a texture whose threads call for investigation. Einstein's affiliation of space with time was the most mind-satisfying of all merely scientific ideas, and his unified field theory was the next logical advance; the quantum must shortly be drawn into it.

In the restricted sense of physical science and, therefore, with due deference to the "lap of the gods," complete knowledge of the non-living physical world is not forbidden. If it were reached then all the energies of the mind would be freed for the development of the more real world of the spirit.

The distinction between physical and spiritual is, no doubt, artificial and temporary, for it belongs to discontinuity, but human progress always has been by steps, and though each step has been false in content it has been true in trend and progress has been real.

THE PREVENTION OF CRUELTY AND THE WORK OF A GREAT HUMANE SOCIETY

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NATURE breeds life abundantly and destroys life remorselessly. Out of a sunlit sky a winged death falls like an arrow on its prey, and through the darkness death flits on silent pinions. From the branches of trees a furry death drops with tooth and claw, and among the grasses a scaly death with poisoned fang winds its serpentine way. Under the waters glides a finny death, and in the depths gay-colored death awaits with armed tentacles the life on which it feeds. Out of the North death strikes with cold blizzards and out of the South it rides the hurricane. From the storm clouds death sends its lightning, and from the sun issues death by heat stroke. With famine and thirst death reaps the harvest of life, and in the food she tenders to life lies death in poison, toxin and unbalanced and deficient nourishment. These are the clubs with which nature beats down life spectacularly.

More insidious and less spectacular, as a rule, are the weapons with which nature most often destroys the life she breeds. Death lurks in crawling ticks and mites and rides the air in mosquitoes and flies. It steals into its victims in worms that drain their life blood and sap their vitality. In protozoan parasites it enters the blood stream or invades the tissues. It resides in bacteria too small to see except with the microscope, and lies concealed in viruses that defy the microscope to detect them and the filter to stop them. And if these fail, an inevitable death walks hand in hand with an unavoidable old age.

These deaths stalk among the farmer's herds and flocks and take their yearly toll by hundreds of thousands. They filch from the farmer millions of dollars. And where death's weapons are too dull to kill, they leave their mark in unthriftiness and illness for which the animals pay in suffering and the farmer pays in lost income and costs of feed and treatment. To protect his animals from death and disease the farmer must throw around them as many safeguards as possible. They must be protected against inclement weather, against predatory animals, against famine and bad feed, against thirst and bad water and against disease.

To the deaths and suffering which nature inflicts must be added the deaths and suffering which man inflicts. Man is an animal, and as such he must feed as animals feed. He must eat animals or plants, and for the most part he either must eat animals or elects to eat animals as part of his food. His digestive tract is that of a meat-eater, a rather short and simple digestive tract suitable for the digestion of the concentrated food which meat provides. His simple stomach resembles that of the dog and is in marked contrast to the four-part stomach of the sheep and cow which provides storage in two relatively huge compartments for the large amount of grass which is hastily collected and later regurgitated and chewed in rumination. His small intestine is like that of the dog and is a short affair as compared with the 85-feet long intestine of the sheep. His large intestine and cecum, like those of the dog, are insignificant when contrasted with the enormous colon and cecum of the horse with their many gallons of plant ingesta. Nature has laid on the human animal the compulsion to kill for his food, and while an individual here and there may elect to take the lives of plants only, instead of the lives of animals, the human race, by and large, eats meat and takes the lives of animals from necessity or choice. He must take life to live, or else follow nature's kill and live as a scavenger.

To a far lesser extent than nature, man inflicts suffering on animals. As a hunter he may wound game that gets away. In other fields he may neglect his domesticated animals, or abuse them with whip or spur. Needless cruelty has been too common. It is no far cry from our civilization to our former savagery. We are not remote from the time when man was a relatively weak animal surrounded by dangerous and powerful enemies, and when he had to strike back as best he could against cruel foes. In such circumstances it was unlikely that he would lament the blows he inflicted on the enemies that sought his life, nor is it surprising that he should still assert, sometimes remorselessly, the authority he has won against a hostile world that sought his destruction. He, too, is beset by death from fang and claw, from cold and heat, from famine and thirst, and from disease and old age. Against death from all these things except old age he must fight back if he is to survive in a world where life is still a struggle for existence.

But as man emerges from savagery to civilization he develops an increasing kindness and compassion. Self restraint leads him to avoid the infliction of needless suffering. Through education he develops kindness in children. By law he restrains those who would wilfully or carelessly inflict cruelty if left to themselves. These are the voluntary and imposed restraints on man to prevent cruelty by man.

But these cruelties inflicted by man are relatively few and isolated acts by comparison with the wounds which nature inflicts on the innumerable animals she spawns. In the endless battle of life with death, man can play only a small and carefully selected rôle. It is one thing to step between a man and the dog he intends to kick, but it is something else to interfere in the rolling tide of battle where individuals perish by millions daily. We have been none too successful in preventing the needless cruelty of recurrent useless human wars; we could only stop nature's destruction, if it were possible, at our peril. For death and decay are nature's devices for preventing an overcrowded world and making possible her endless experiment in the breeding of new life with the potentialities for new things. Without the intervention of death, a single species of many kinds of animals could very speedily overrun the world. It is no misfortune that man can not step into this whirl of death and bid life live immortally, for he would be buried in the swift flood of life that would rise from such an act.

Man's interference with nature's laws of life and death, his intervention to prevent suffering, must be selective and intelligent to the extent that we have attained intelligence. Could he deprive the tiger and eagle of their prey, he would only condemn tigers and eagles to suffer and perish from starvation, and any wide application of the vegetarian cult would condemn the carnivores and many omnivores to death. Could he save from birds and other animals the insect life that spawns so abundantly, he would not only starve the insect-eating birds and other animals, but he would bring on his head destruction from swarms of insects.

In most of his interference with nature, man seeks to benefit man. In self-defense he destroys carnivores and poisonous snakes. To protect his crops he traps and poisons insects and rodents. To protect his livestock he builds shelter from storms, provides feed for winter and water for times of drought, dips cattle for ticks and sheep for scabies, practices swine sanitation to protect his swine from worms and filth-borne diseases, and in other ways prevents accidents and disease from injuring and killing the animals on which he depends for food, clothing and work.

Not to interfere with nature in the interest of man would be to subscribe to some fatalistic and esoteric doctrine that regards the welfare of man as of no importance or as something to be left to nature's discretion. Had primitive man adopted such an attitude there would have been no race of mankind to attempt such an attitude to-day. Primitive man fought against the forces that sought to destroy him, and modern man must do the same. If here and there some one wishes to take sides with nature, he can do so as an academic pastime, since the bulk of humanity will continue to behave in a way that protects these odd and exceptional persons. Such persons are dangerous only as they seek to make the rest of mankind conform to their peculiar philosophy.

Of the suffering and death which nature inflicts on man's livestock, the most important is inflicted by disease. To the casual observation of the humanitarian untrained in medical matters, the blow of a whip on a horse or the kick inflicted on a dog is an outstanding piece of cruelty that calls to heaven for interference. That such conduct calls for action to protect animals from cruelty and mankind from the sadistic psychology of cruelty is a matter of general agreement. But to the veterinarian or the thoughtful stockman the suffering from disease is a much more wide-spread and serious thing than the relatively rare infliction of cruelty on animals by brutal or careless persons.

The list of diseases from which animals suffer is a long one. The symptoms produced by disease are innumerable and sometimes extremely painful, as all persons who have suffered from certain diseases know. It is a painful thing to have a diphtheritic death clutch the throat and choke out the life, to have death grasp and still the heart, to suffer the fever and pain of peritonitis or the agony of trichinosis, or to die the terrible death of rabies or tetanus. But in one way the animal has the advantage over man. It does not know the concept of death nor have the realization that the end of life is approaching.

Numerous agencies have engaged in the effort to lessen the sum total of suffering and premature death among mankind and the lower animals. The church has preached kindness, the law has forbidden cruelties, and humane societies have intervened between oppressed and mistreated children and animals and their oppressors. These agencies deal with the small body of cruelties inflicted by man. Against the large body of cruelties inflicted by nature stand the great groups of physicians, veterinarians and scientists. Here are the groups that oppose nature's array of hostile forces when these forces are directed against man, his domesticated animals, his game and game birds, and his fur-bearers, fish and other useful animals.

In the warfare against disease the army of physicians and veterinarians maintains a force of combat troops on the firing line, the practicing physicians and veterinarians who engage disease and death at close quarters and fight for the health and lives of man and animals. A service of supplies brings to these troops the drugs, biologicals, new information and other weapons for the attack on viruses, bacteria, parasites, poisons and the other troops which death marshals against man and his animals. And at the base are the ammunition factories forging old and new weapons for the fight. From tropical forests comes the material for the making of quinine for the combat with malaria, and from deep mines comes the arsenic from which will be made arsenicals for the combat on the far-flung fronts of syphilis, sleeping sickness, and cattle ticks and cattle-tick fever. In numerous laboratories, physicians, veterinarians and scientists quietly and persistently maintain the intelligence service which studies the forces of nature, spies upon her deaths and diseases to find the disposition of her lines and the weaknesses in her forces, and tests experimentally new weapons and new plans of attack on the captive forces of the enemy caged in test-tubes and experiment animals.

The world at large knows and appreciates the combat forces of the practicing physician and veterinarian. It understands that the materials for drugs are collected from far and wide and manufactured for the use of these combat forces. But it knows little of the research of the intelligence service that studies the forces of death and disease and plans new weapons. Now and then it learns from the press that a Lazear has died in a heroic proof that a certain mosquito carries the deadly yellow fever, that the field forces of the Public Health Service have lost three workers to the Rocky Mountain spotted fever with which they worked, that Francis and Lake have contracted the tularemia they were investigating, or that some courageous experimenter with radium has yielded an arm to the enemy on which he spied. For a moment a glimmer of appreciation of these soldiers of the secret service rises in the reader, but this soon dies down, and, when some fanatical opponent of this service approaches him with the tale that all such work has led to no result whatever, he carelessly puts his name to a petition that the laboratories be closed, and in so doing votes that disease and death be allowed to work their way with man and animal except as they may be fought with yesterday's weapons.

Foremost of those who would close the search for knowledge and write "Finis" to the rapidly growing book of medical science is the group of men and women who call themselves antivivisectionists. About a nucleus of paid propagandists clusters this medley of kindly but poorly informed humanitarians, enemies of all medical science, sadists who conceal under an outward love of animals a cruelty towards mankind, persons who boldly flaunt the conviction that they would rather see a child die of disease than have a guinea-pig subjected to experiment to find a way to save the child, persons who admit that they would rather see a million dogs die from parasitism at nature's hands than have a hundred dogs subjected to studies on that parasitism by scientists to save the million dogs, and persons whose qualification for passing judgment on medical work is the qualification of an advertising man, a minister, a poet, an author or an actress. This group is the outstanding group of nature's allies in the fight between man and nature's forces of disease and death. They are the enemy aliens who would blow up our laboratories and our ammunition plants, who would cut our service of supplies to the firing line, and who would leave our fighting forces to oppose to the incessant fire of nature's forces the ancient and rusty weapons of Hippocrates and Dioscorides. They do not hesitate to declare the immeasurable services of a Pasteur things of no value; they do not hesitate to tell the medical man and veterinarian who have seen the deaths and suffering of rabies that there is no such thing as rabies; they do not hesitate to tell us who in childhood saw innumerable persons with faces scarred with smallpox pits and who now rarely or never see such faces, that vaccination is a crime. Year after year these persons hear the evidence of the benefits to mankind and to animals from experiments on animals and, year after year, with characteristic intellectual dishonesty, they reiterate the falsehood that no benefits ever came from experiments on animals. It means nothing to them that the disease and death which man deliberately inflicts on a hundred guinea-pigs or dogs to-day save the health and lives of a million persons or dogs or cows next year or in the next ten years. They cast their lot with nature's cruelties and disease and premature death on a large scale; the medical man and scientist cast their lot with man for the frustration of nature's cruelties and the prevention of disease and premature death on the large scale of nature. The antivivisectionists shut their eyes to nature's cruelties; they are not so concerned that man and animals suffer, but they are eager to lay their heavy hands on the work of scientists and to choke to death the sources of information as to how nature fights man and how man may best fight nature.

Whence came the weapons with which modern man fights nature's infliction of suffering, disease and death? Did any of them come from the antivivisectionists? Not one of them. They came from medical men and scientists. These are the workers who forged the weapons with which man fights smallpox, tetanus, anthrax, syphilis, tuberculosis, malaria and pellagra in man, and tick fever, blackleg, blacktongue and parasites of all sorts in his animals. The army of medical men and scientists on the firing line, in the service of supplies, and in the intelligence service asks the people whom it serves to protect that army in its fight against suffering, disease and death from the antivivisectionists who would deprive it of its weapons. It is preposterous that the medical men who have protected the public from birth, who have come to its rescue when nature struck at it with all the forces at her command, who have gone through the wintry night to sit at its bedside and bring it back from the shadow of death, should have to ask the public to protect it from the insidious attacks of a small minority of uninformed persons who ridiculously put out misrepresentations on the highly technical subjects of a medical science in which they are untrained and of which they are ignorant, but it is the inevitable weakness of democracy that highly vocal groups of persons may at will seek to impose their ideas on the public, and that numbers may outvote ability and competence.

The medical man must not only fight suffering, disease and death, but he must take from that fight the time and energy to fight ignorance and prejudice, the alien enemies who would tie his arms. And with characteristic logic the antivivisectionist resents the effort of the medical man and scientist to fight off these attacks. With astounding effrontery the leader of the antivivisectionists protested to the chairman of the senate committee in the District of Columbia at the hearing on the bill to prevent experiments on dogs, that government scientists came from their laboratories to oppose this bill which would stop their investigations of disease. Could illogical audacity exceed this assumption that scientists should sit abashed in their laboratories while women under the gonfalon of humanitarianism labored to persuade Congress to undermine the legislation which charged these scientists with the study of disease and the development of control measures?

In the lesser field of cruelties inflicted by man the humane societies of the United States have done an admirable work. In the greater field of cruelties inflicted by nature there is a great humane society that has done a wonderful work. That humane society is the federal Bureau of Animal Industry. Its record of achievement as a humane society has not been written, and it is here proposed to put that record on exhibition in contrast with the record of the antivivisectionists and as a record of work that supplements in preventing nature's cruelties the work which humane societies have done in preventing man's cruelties. There is no conflict between humane societies on one hand and scientists, physicians and veterinarians on the other; they supplement one another and they cooperate with one another. It is only between the antivivisectionists on one side and medical men and scientists on the other that war exists. It is true that the antivivisectionists have managed to enlist the support of many humane societies by representing the medical man and scientist as vicious, cruel and debauched persons who inflict wilful suffering to no purpose and for their own enjoyment. It is true that antivivisectionists have done this, but it is deplorable as the results of misrepresentation are usually deplorable. Let the humane societies judge the record of the Bureau of Animal Industry, one of the organizations which would suffer from antivivisectionist legislation, and say if the humane societies and the bureau are allies or enemies.

The Bureau of Animal Industry had its beginning in 1883 with the appointment of an able veterinarian and scientist, Dr. D. E. Salmon, as the head of a veterinary division. That same year it established two research units, a pathological laboratory and its experiment station. In 1886 it established the work in parasitology which later developed into its zoological laboratory, and in 1890 it established its biochemical laboratory. It is proof of Dr. Salmon's sagacity that at the very outset he took cognizance of the fact that our ability to combat disease was entirely dependent on our knowledge of disease, and that he should organize medical research to supply the vital information which we did not have for our attack.

Did anything of value to humanity, and especially to the farmer and stockman, come from these research laboratories? Let the following record answer the question.

In 1889 Dr. Kilborne obtained experimental evidence that cattle tick fever could be transmitted from cattle sick with this fever to healthy cattle by means of the cattle tick, *Boophilus annulatus*. In the same year Dr. Theobald Smith, of the Pathological Division, published the fact that the tick fever was caused by a protozoan organism in the blood, and he and Kilborne showed that the organism was transmitted through the egg of the tick which had fed on cattle sick of the fever. This brilliant and classical piece of work laid the foundation for the later work on the transmission of malaria and yellow fever by mosquitoes, sleeping sickness by tsetse flies, typhus fever by lice, Rocky Mountain spotted fever by wood ticks, tularemia by deer flies, and other disease agencies by insects and ticks. How was this work done? By animal experimentation. A few head of northern cattle were exposed to the bites of infected ticks, and these cattle sickened of the fever and showed the parasite in the blood. About the same time Dr. Curtice, of the Zoological Laboratory, ascertained the life history of the cattle fever tick—by animal experimentation. Subsequently Ransom and Graybill in the zoological division standardized the arsenical dip so that it would kill ticks and would not kill the cattle which were dipped in it—by animal experimentation. Did these experiments on animals result in any benefit to man or animals? Consider these facts:

Tick fever had been enzoötic throughout the South for many years, and every year northern states suffered severe losses from the deaths of cattle exposed to the attack of ticks carried North in drives and shipments of cattle. The area in which tick fever was enzoötic, comprising all or part of fifteen states, was quarantined south of a line extending from Virginia to California and, in 1906, the systematic dipping of cattle to destroy ticks was begun by federal and state forces along the northern border of the quarantine line. At the present time tick fever and cattle ticks have been driven from eleven states and remain only in areas in four states, Florida, Louisiana, Texas and Arkansas. In 1905, the year before Congress made its first appropriation for federal tick eradication, the death losses from cattle tick fever were 387,500 head of cattle annually out of over 1,500,000 cases of tick fever. The losses from death, sickness and unthriftiness associated with cattle tick and cattle tick fever aggregated about $40,000,000 annually. Within 22 years after the inauguration of federal tick eradication, ticks and tick fever had been wiped out over an area of more than 500,000 square miles; to-day over 600,000 square miles have been released from quarantine. Experiments on the few animals used by the bureau had resulted in saving the lives and protecting the health of millions of cattle year after year. These experiments had saved the southern farmer millions of dollars annually and had enabled him to improve his stock in a way impossible under the menace of the tick. Within a few years cattle ticks and tick fever will be a thing of the past, and none of the South's cattle will ever know the suffering or experience the deaths that millions of cattle have suffered there from those things.

Does this mean anything to the antivivisectionist? No; he is committed to the statement that no good has ever come from experiments on animals, and he must not and can not admit that the classical work of Smith, Kilborne, Curtice, Ransom and Graybill has led to any benefit. He must and does contend that it was of no value. He must contend that Congress was deluded when it brought into existence a Bureau of Animal Industry that would experiment on animals as a basis for a brilliant campaign that has driven from most of the South the greatest menace to its livestock industry.

In 1896, shortly before these experiments on cattle tick and tick fever were undertaken, the antivivisectionists had introduced into Congress a bill to prevent experiments on animals. Could they have had their way they would have prevented this work, doomed the cattle of the South to many additional years of suffering and premature death, and condemned southern agriculture to share its livelihood with the tick and the fever. In 1930 they stood before Congress where they stood in 1896, on the platform that it is better for nature to destroy a million animals than for man to destroy a few and save millions. They had failed to stop the work on tick fever, but they hoped to stop future work. The scientist still stands where he stood in 1896, on the platform that if he can pay one life to save a hundred, a thousand or a million he will pay that life and save those lives. He realizes that nature still has many weapons against which we have no defenses, and that we can build those defenses only by experiments on animals.

In the control of hog cholera, the Bureau of Animal Industry has again played the rôle of humane society. Hog cholera has been known in the United States for almost a century. As early as 1867 it caused the deaths of 15 to 60 per cent. of herds of swine in the area in which it occurred, and these deaths represented a loss of $15,000,000 to the farmer. In 1905, Dorset, McBryde and Niles, of the bureau, by experiments on swine developed a serum treatment for the protection of swine against hog cholera. This method of treatment by serum, or serum and virus, represents the only effective line of control in outbreaks of hog cholera. The sacrifice of the health and lives of a comparatively small number of swine has saved the lives of millions of swine and has saved the farmers millions of dollars. In 1913, before the division of hog-cholera control began work, over 6,000,000 swine, worth almost $60,000,000, died of hog cholera. In 1929, less than 2,000,000 swine, worth about $22,000,000, died of hog cholera. These comparative figures represent a saving of over 4,000,000 animals and $38,000,000. Will the antivivisectionists say that this work was of no value? Certainly they will. They are committed to the thesis that animal experimentation has never developed anything of value and any evidence to the contrary must be rejected by them.

A disease of horses known as dourine was imported into the United States in 1884, and by 1903 it had spread widely over the country. Its control was difficult because of our inability to detect it promptly enough to prevent its insidious spread. By animal experiments the bureau developed an effective complement-fixation test which has enabled it to eradicate this disease from most of the areas in which it was once present, and the small residuum of dourine in the western range horses will presently be wiped out. Will the antivivisectionists contend that the experiment animals should have been spared and the horse population of the United States allowed to suffer from our lack of the knowledge derived from animal experiments? They will.

Scabies in sheep is a disease which was known to the ancient world, and the use of scabby sheep as sacrifices to Jehovah is forbidden in the Bible. Thirty years ago scabies was the outstanding pest of the sheep industry of this country. It was absolutely ruinous to the wool crop and it killed large numbers of sheep, forcing many sheepmen out of business. Its cause, mode of transmission and its treatment were ascertained by animal experiments, some of them in the Bureau of Animal Industry. As a result of these experiments and the application of the knowledge obtained from them scabies has been eradicated from such important sheep-raising states as Montana, Idaho, Nevada, Oregon and Washington, and as a sporadic affair here and there it has fallen in importance far below many of the other sheep parasites for which we have inadequate control measures today. If we are to have control measures for these other parasites we must develop them as we developed control measures for scabies, by animal experiments, but the antivivisectionists would stop all experiments on animals as rapidly as their propaganda became effective, and leave sheep to die from blood-sucking worms. That the farmer would pay a heavy bill for this amazing form of alleged humanity does not matter to them. Let the scientist learn what he can by watching nature destroy sheep and guessing how she does it, but he must not produce disease under the controlled conditions which make possible a definite knowledge of how it is produced. Let the veterinarian treat sheep with such treatments as were known to Abraham, but forbid him to test new treatments, for that is an experiment on animals. Such arguments may delude poets and actresses; it is unlikely that they will delude stockmen and farmers who suffer the losses from disease in their flocks and who have the pride in healthy and thrifty livestock that characterizes the sound husbandman.

At the beginning of this century tuberculosis in cattle was prevalent in every state of the union. At the Soldiers' Home in the national capital the milk supplied our veteran soldiers came from a herd of which 84 per cent. of the animals were tuberculous. By means of animal experiments in Europe, a diagnostic agent known as tuberculin was developed; by animal experiments in the bureau it was improved, and the Bureau of Animal Industry led the way in a nation-wide campaign to eradicate this disease. The herd at the Soldiers' Home was the first tuberculosis-free herd in the country. To-day the incidence of bovine tuberculosis is about one third of what it was in 1916. Three states are practically free from bovine tuberculosis, and in many states there are large numbers of clean herds and large accredited areas in which there are nothing but clean herds. There are 1,124 counties which are modified accredited areas with nowhere over 0.5 per cent. of tuberculosis. The per cent. of tuberculous cattle found at the packing plants has fallen off to one third of the amount previously found. Simultaneously there has been a sharp drop in the incidence of intestinal tuberculosis in children and other forms of juvenile tuberculosis, correlated with the decrease in the proportion of our supply of raw milk coming from tuberculous animals. This victory over the white plague was won with weapons developed by experiments on animals. Thousands of animals and persons have benefited for every experiment animal used. The antivivisectionist prefers tuberculosis to experimentation; normal persons in general will prefer that a smaller number of experiment animals die from tuberculosis that a larger number may live free from tuberculosis.

A somewhat similar story could be written about practically all the diseases of animals with which the Bureau of Animal Industry deals. Practically all the sound information we have in regard to the transmission and control of disease in these animals came from experiments on animals carried out either in the bureau or elsewhere. The bureau would not dare to ask Congress for money with which to start a tick-eradication campaign, a tuberculosis-eradication campaign, a hog-cholera-control campaign, or any similar campaign until it had this basic information from animal experimentation. Only after a control measure has been shown to work on experimental animals can it be recommended and put to work on a nation-wide scale. Irresponsible persons who need not account to the livestock industry for their ignorance can propose legislation to destroy the safeguards which the Bureau of Animal Industry throws around the livestock of the country, and if the legislation is enacted and disaster follows, these irresponsible persons can not be brought to task. The farmer would pay for their mistakes in cash and their animals would pay in suffering and death, but this would not worry the misguided enthusiast who wears the halo of the reformer. If they can make the world safe for experimental animals, disease in livestock may rage and agriculture be ruined. If the Bureau of Animal Industry makes mistakes it can be brought to account; it is a responsible organization, created by Congress, endowed with responsibility by Congress, and accountable to Congress. Will Congress, the American farmers and stockmen, and the public support the Bureau of Animal Industry in maintaining the laboratories which have served them in the control of disease and have saved them millions of dollars, or will they take the word of antivivisectionists that these laboratories have achieved nothing and leave the antivivisectionists to prescribe the measures for the control of disease? Will the American people rush to the rescue of the scientist's guinea-pig or dog at the call of a frenzied antivivisectionist, and ignore the people, the livestock, the dogs and other animals that the scientist would save? Will they believe that all the testimony of the Bureau of Animal Industry, the Public Health Service, the American Medical Association, the American Veterinary Medical Association, the American Association for the Advancement of Science, and of other professional and scientific bodies that deal with science is false when these groups tell them that animal experimentation is the only means to learning the control of disease? Will they believe that Osler, Welch, Hektoen, Keen, Sternberg, Reed, Senn, McCoy, Stiles, Goldberger, Francis, Salmon and Mohler were liars when they testified what great good had come from experiments on animals? Will they believe the distinguished scientists Pasteur and Koch—or Mrs. Brown, Miss Jones and Mr. Smith, the antivivisectionists? Will they listen to evidence by the physician and veterinarian, or will they follow the war-whoop of the propagandists?

The humane societies of the United States put to death as painlessly as possible thousands of stray dogs annually, in order that these homeless animals may not suffer or perhaps perish more miserably than they do in the gas chamber. This is done as a kindness, and doubtless it often is a kindness, although under somewhat similar circumstances man prefers to cling to life, however miserable, and rarely elects death, voluntarily, as a release from the hardships of life. Probably if we consulted him, a homeless cur would elect to go his way and live from garbage cans. The problems of life for man or dogs are a bit complicated, and in a world of complications and uncertainties it is easy to mistake kindness for cruelty and cruelty for kindness. The antivivisectionist mistakes these things habitually.

The Bureau of Animal Industry, acting in its capacity as a humane society, also takes the lives of animals, but with less uncertainty as to benefits than is involved in destroying stray dogs, and with an objective which goes beyond that of our humane societies in general. In 1843, contagious pleuro-pneumonia of cattle entered the United States. In 1886, the young Bureau of Animal Industry had to drive this enemy of our livestock industry from the country. There was no cure for the disease. To eradicate it, the bureau killed every animal sick of the disease, the last animal being killed in 1892. From that year to this, there has been no contagious pleuro-pneumonia in the United States, and a vigilant quarantine by the bureau keeps that disease from the country. Had the bureau spared those cattle it slaughtered, there would have been by now almost 40 years of suffering and death among our cattle that have been averted by the bureau, almost 40 years of losses to the farmer that have been saved by the bureau. Was this destruction of sick cattle a humane and intelligent act? Does this compare favorably with the work of humane societies in general? Does it appear that the personnel of the bureau is interested in saving the lives of animals, or does it appear that it is composed of cruel and wanton persons?

On six occasions, the bureau has stamped out foot-and-mouth disease by slaughter in order that our herds might be free from this disease. Is this humane? Would any humane society have acted differently? Yet the antivivisectionists ask the humane societies to believe that the bureau harbors a personnel that delights in cruelty.

There was a time when livestock was carried on freight trains for days without being unloaded, suffering from confined quarters and often inadequately provided with food and water. Did the humane societies abolish this practice? The one we have referred to as a great humane society, the Bureau of Animal Industry, did. Yet, under the pretense of a regard for animals, the antivivisectionist attacks the bureau as an inhumane organization.

There was a time when animals at packing plants were prodded and clubbed by stupid employees. The bureau stepped between these animals and their oppressors and forbade this cruelty. It insisted that animals for slaughter be handled humanely and killed as rapidly and painlessly as possible. Were these the acts of a cruel organization? No other humane society, nor all other humane societies together, can show so many animals protected from human cruelty as can the Bureau of Animal Industry. But the antivivisectionists would have you believe that the veterinarians and scientists of the bureau are fiends in human form.

Whether from the individual cruelty of man to animals, or from the thousandfold cruelties of nature to animals, the Bureau of Animal Industry protects many more animals than do any or all other humane societies. In its fight with human cruelty it invokes the law more surely than can other humane organizations. In its vastly greater fight with disease it uses whatever weapons are available. When science has afforded the weapons, it uses the dipping vat, tuberculin, serum, drugs, sanitation or other agencies. When there is no weapon from the research laboratory, as was the case with pleuro-pneumonia and foot-and-mouth disease, it uses the rifle. But there is no mistaking its objective. It was organized to protect the lives and health of animals, and that is its aim. Its regulatory work, its research, its experiments on animals, all have that goal in mind. Its procedures trace back inevitably to a research laboratory and to experiments on animals. To ban those experiments is to wreck its laboratories, and to wreck its laboratories is to destroy the foundation on which rests all its other work. The humane societies of the United States have the same goal as the bureau, the prevention of suffering, but the goal of the antivivisectionist is the prevention of knowledge of how to relieve suffering.

THE DIUTURNAL USE OF PERFUMES AND COSMETICS

By GRACE M. ZIEGLER

TRENTON N. J.

"LADIES, beauty is a Blessing of God, and every one ought to preserve it, in fine, they do as much offend that neglect it, as they do that Paint their Faces." This advice was offered in 1686 by Dr. Stephen Draper in an advertisement addressed to: "Beloved Women who are the Admirablest Creatures that ever God created under the Canopy of Heaven, to whom therefore, I have devoted my studies to the preserving of your Beauty, Health, Vigour, Strength and Long Life."

When one considers the annual cost of cosmetics for women, and men, too, throughout the ages, such counsel appears superfluous. The prodigious use of perfumes and cosmetics at the present time—running into hundreds of millions or perhaps billions of dollars—to secure a uniform standard of attractiveness might appear on the surface to be another instance of the modern trend toward standardization. That such a trend, so evident in the business world, is not responsible in this case is shown by the fact that a standard of personal beauty has been established and pursued as far back as any trace of human activity can be found. At times in the past this form of luxury far outstripped any present extravagance.

The tendency to legislate against any and every habit is another ancient custom, and it may be only a matter of time before another attempt is made to prevent the use of artificial aids to attractiveness. More than twenty-five hundred years ago a law was promulgated by Solon to prohibit the sale of fragrant oils to the men of Athens, and from then on similar bills have been introduced, among them one in England, in 1770, providing that:

> All women, of whatever rank, profession or degree, whether virgins, maids or widows, that shall from and after such Act, impose upon, seduce and betray into matrimony, any of his Majesty's subjects by the scents, paints, cosmetic washes, artificial teeth, false hair, Spanish wool, iron stays, hoops, high-heeled shoes, and bolstered hips, shall incur the penalty of the law now in force against witchcraft and like misdemeanours, and that the marriage upon conviction shall be null and void.

Although this did not become a law, it had a sobering effect upon the populace for a number of years. Surprisingly, Beau Brummel was opposed to the use of perfumes, on the ground that "No man of fashion should use them, but should send his linen to be washed and dried on Hampstead Heath."

From the earliest times, religion has vied with personal adornment in the consumption of perfumes. The use of costly ointment by Mary to anoint the feet of Jesus was but an echo of religious customs of the past. If sweet-smelling odors were so pleasing to man, would they not be the most effective method of propitiating the gods? That they were was a fixed belief for centuries, and there are many evidences that the use of perfumes and unguents formed an important part in the spiritual life of man.

A papyrus in the Hermitage Museum, said to have been written about 2000 B. C., contains in an account of the writer's journey into Nubia the statement:

> I will cause to be brought unto thee fine oils and choice perfumes, and the incense of the temples, whereby every god is gladdened. Of

> myrrh hast thou not much; all that thou hast is but common incense. Ashipu came and delivered me, and he gave me a shipload of myrrh, fine oil, divers perfumes, eye-paint and the tails of giraffes.

One of the earliest recipes for making perfume, of which we have record, is given in the Book of Exodus:

> Moreover Jehovah spake unto Moses, saying, Take thou also unto thee the chief spices: of flowing myrrh five hundred shekels, and of sweet cinnamon half so much, even two hundred and fifty, and of sweet calamus two hundred and fifty, and of cassia five hundred, after the shekel of the sanctuary, and of olive oil a hin; and thou shalt make it a holy anointing oil, a perfume compounded after the art of the perfumer: it shall be a holy anointing oil.

This oil was to be used for anointing the tent of meeting, the ark of the testimony, table and candlesticks, altar and laver, thereby making them holy so that whatever touched them became holy. Aaron and his sons were anointed with it, to minister unto Jehovah in the priest's office, but any one else who made or used a similar compound was to be "cut off from his people."

A recipe for incense is given in the same chapter:

> And Jehovah said unto Moses, Take unto thee sweet spices, stacte, and anycha, and galbanum; sweet spices with pure frankincense: of each shall there be a perfume after the art of the perfumer, seasoned with salt, pure and holy: and thou shalt beat some of it very small, and put of it before the testimony in the tent of meeting, where I will meet with thee: it shall be unto you most holy. And the incense which thou shalt make, according to the composition thereof ye shall not make for yourselves: it shall be unto thee holy for Jehovah. Whosoever shall make like unto that, to smell thereof, he shall be cut off from his people.

As perfumes were considered a most acceptable offering to the gods, vases were buried with the dead for their use in obtaining favor from the deities. Beautiful containers of alabaster and vases of diorite and other costly materials were provided with stoppers or lids to preserve the contents from deteriorating. The success of their elaborate efforts was shown when the opening of King Tutankhamen's tomb revealed exquisitely carved alabaster vases in which, after more than three thousand years had elapsed, the scent of the perfume still lingered.

We are told by Pierre Muret[1] that it was "an ancient Christian custom to perfume the body in commemoration of the spices in which the body of the Savior was wrapped, and that the pagans, who much prized perfume and used it in their religious rites and copiously on their bodies, much chided the Christians for wasting precious ointments on their dead at the expense of the living." The custom of perfuming the body of the deceased, however, was practiced many centuries before the time of Christ. The accompanying illustrations (Figs. 1 and 2) show the process of embalming Egyptian mummies, which for the richest people included filling the head with drugs and substituting for the intestines powdered myrrh, cassia and other perfumes (except frankincense). An address to the deceased, translated by Maspero, is as follows: "The perfume of Arabia hath been brought to thee, to make perfect thy smell through the scent of the god. Here are brought to thee liquids which have come forth from Rā to make perfect—thy smell in the Hall [of judgment]." It was thought that through the perfume the members of the body were made perfect.

The word "perfume" is from the Latin *per fumum*, meaning "through smoke." Doubtless the earliest use of perfumes was to serve as a means of communication with the gods, prayers being wafted upward on the sweet-smelling fumes, thus insuring more favorable reception. The Egyptians made a prayer to Rā that the souls of the de-

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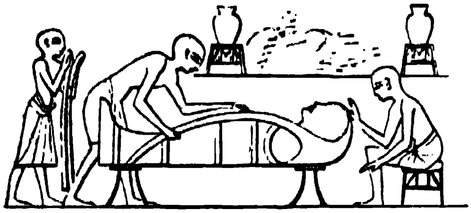
[1] Pierre Muret, (Tran. P. Lorraine), "Funeral Rites, Ancient and Modern."

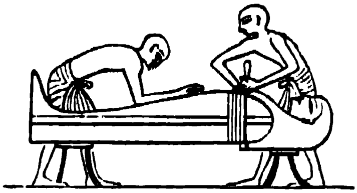


PERFUMING THE BODY OF AN EGYPTIAN MUMMY
(FROM "THE BOOK OF PERFUMES" BY EUGENE RIMMEL. LONDON, 1865.)

parted be carried to heaven on the smoke of the incense.

Perfumes also played an important part in many of the magical rites from the earliest times down to those practiced by the barbaric races to-day. In the sixteenth century Henry Bouguet discussed this subject under the heading "Of the Perfumes Used by Priests in their Conjurations."[2]

> It remains for us to show that it is not out of place for our priests to use perfumes in their exorcisms: and this will be very easy. I will readily admit that perfume has no direct virtue against the Evil Spirit, since he has no body and consequently no sense of smell: Yet it must be granted me that this wicked Serpent is very glad to find in the bodies of men humours which the more dispose them to be tormented by him, the chief of these being the melancholy humour, which is of its nature apt to be heavy and sad; and therefore we find that those of a melancholy humour are more often possessed by a devil than are other men.
>
> Now it is certain that there are perfumes which consume and correct these humours, for even sulphur works in a very subtle manner to that effect; and therefore I conclude that the Devil will be more easily cast out of a demoniac's body if it be purged of the humours of which we have just spoken, than if it be still charged with them. I am strengthened in this belief by the fact that Holy Scripture teaches us that the Evil Spirit is more glad to be in one body than another, as we see in St. Mark, where the devils, being commanded by Jesus Christ to come out of a man's body, asked to be sent into some swine. It follows, therefore, that the perfumes of our priests must not be decried, since they are, in some manner, of use against devils. This is even better shown by the example of the youth Tobias, who drove away the Devil with a perfume which he composed from the heart and liver of a fish. It is true that he accompanied this with prayers and fasting; but do not our priests the same? There is no doubt, also, that perfumes which are hallowed by the Word of God are of greater virtue against the Devil than such as are used in their own natural state; and therefore Origen, speaking of perfumes and incense, says that the sanctification by the Word of God, with Holy Prayer and the help of the Angels, is the reason for perfume and incense driving out demons.



BINDING THE BODY OF AN EGYPTIAN MUMMY AFTER IT HAD BEEN PERFUMED
(AFTER RIMMEL.)

> But who will contradict me when I say that God endows these perfumes with a supernatural power against demons and their works, seeing that we have already mentioned certain stones and herbs which drive away all spells and enchantments? For that He may the more manifest His Majesty, God wishes to fight and overcome demons by means of these insignificant things, just as He put Pharaoh's magicians to shame when they tried to create flies; for although they, as well as Moses, had made frogs and serpents and dragons, yet they could not succeed in making these small and minute little creatures.

Other purposes, too, have been served by the use of perfumes. Society ladies in the eighteenth century are said to have "painted their faces instead of washing them, and mitigated the effects of seldom-changed underclothing by copiously drenching themselves with musk and other reliable perfumes."

Two centuries ago the pompous doctors carried musk, camphor or other aromatics in the hollow handles of their walking sticks to hold to their noses and protect themselves from the dangers of infection. In medieval, Jacobean and Georgian medicines, fumigation was a favorite remedy. Perfumes and aromatics were extensively used in the medicines in those days.

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[2] Henry Bouguet, "An Examen of Witches," Lyons 1590? Trans. E. A. Ashwin, New York, 1929.

As "Cures for Head-Melancholy" Robert Burton in "The Anatomy of Melancholy" prescribes:

> Odoraments to smell to, of rose-water, violet flowers, balm, rose-cakes, vinegar, &c., do much recreate the brains and spirits, according to Solomon. Prov. XXVII. 9, "They rejoice the heart," and, as some say, nourish: 'tis a question commonly controverted in our schools, *an odores nutriant*: let *Finicus, lib. 2, cap. 18.* decide it; many arguments he brings to prove it; as of Democritus, that lived by the smell of bread alone, applied to his nostrils, for some few days, when for old age he could eat no meat. Ferrerius *lib. 2. meth.* speaks of an excellent confection of his making, of wine, saffron, &c., which he prescribed to dull, weak, feeble, and dying men to smell to, and by it to have done very much good, as if he had given them drink.
>
> Irrigations of the head shaven, of the flowers of water-lilies, lettuce, violets, camomile, wild mallows, wether's head &c. must be used many mornings together.
>
> Lælius à fonte Eugubinus, *consult 44*, for an Italian count troubled with head-melancholy, repeats many medicines which he tried, but two alone which did the cure; use of whey made of goat's milk, with the extract of hellebore, and irrigations of the head with water-lilies, lettuce, violets, camomile, &c. upon the suture of the crown.
>
> Unto the heart we may do well to apply bags, epithemes, ointments, of which Laurentius, *C. 9, de melan*, gives examples. Bruel prescribes an epitheme for the heart, of bugloss, borage, water-lily, violet waters, sweet wine, balm leaves, nutmegs, cloves, &c.

Among the remedies employed against the plague were many containing sweet essences and aromatic oils, and it is said that the plague water and essences gave the initiative for the invention of Eau de Cologne by the Italian, Johann Maria Farina, who first prepared it at Cologne about 1700. The essences and aromatic oils were evaporated on glowing bricks; whole houses were rubbed down with them, and they were poured on handkerchiefs to be inhaled in the streets. Sometimes incense, juniper berries, lemon and orange leaves, rosemary, lavender, myrrh, etc., were burned in rooms to kill the plague. Scent boxes were sold for use on going out, and some prescriptions called for a scent box for every day in the week, each containing different essences, which were placed on a little sponge. Roses, cloves, juniper, rosewood, sandalwood, lemon peel, etc., were used either as extracts or solids.

The use of perfume for personal pleasure dates from prehistoric times. In the early days it was rivaled as an example of conspicuous waste only by the adornment with precious jewels. As a means of allurement it is apparently without a rival. No one questions the power of an unpleasant odor to repel and nauseate a person, but it is seldom considered that a pleasant odor may have as strong a power to attract. However, in all forms of life scent is thus employed. Flowers send forth their perfumes that insects may be attracted and made to carry out their activities as pollinators. Certain animals from which the "fixatives" in our own perfumes are derived are provided with peculiar scents to attract others of their kind. Japanese beetles and other injurious insects are lured to their death through the artificial employment of their favorite scent.

AN EGYPTIAN LADY AT HER TOILET (AFTER RIMMEL.)

Pliny in his "Natural History" considered the unselfishness of the person using perfumes.

> These perfumes [he wrote] form the objects of a luxury which may be looked upon as being the most superfluous of any, for pearls and jewels, after all, do pass to a man's repre-

> sentative, and garments have some durability; but unguents lose their odour in an instant, and die away the very hour they are used. The very highest recommendation of them is, that when a female passes by, the odour which proceeds from her may possibly attract the attention of those even who till then are intent upon something else. In price they exceed so large a sum even as four hundred denarii per pound: so vast is the amount that is paid for a luxury made not for our own enjoyment, but for that of others; for the person who carries the perfume about him is not the one, after all, that smells it.

Thousands of years ago the trade in aromatic gums and sweet-scented oils formed an important item of commerce between Egypt, Arabia, India and Syria, and they were valued equally with gold and silver. Egyptian splendor was replete with perfumes and scented unguents. Houses were perfume scented; the people were commanded to perfume themselves every Friday; food, wines and delicacies were flavored with perfume; during festivals incense was burned in the streets to permit even the poor to enjoy the exquisite fragrance; the men used scented unguents for their bodies and the women bathed in perfumed waters. The guests at banquets were met by slaves whose duty it was to anoint their heads with perfumed unguents and hang chaplets of lotus around their necks. Perfumes continued to grow in favor until in Cleopatra's time it is not surprising that she used them lavishly to add to her allurements and charm. It is said that "She used the worth of 400 denarii of spices but once, to anoint her hands, which was wafted away on the air and lost for ever." Of the barge she used when sailing down the River Cydnus to meet Mark Antony, Shakespeare writes:

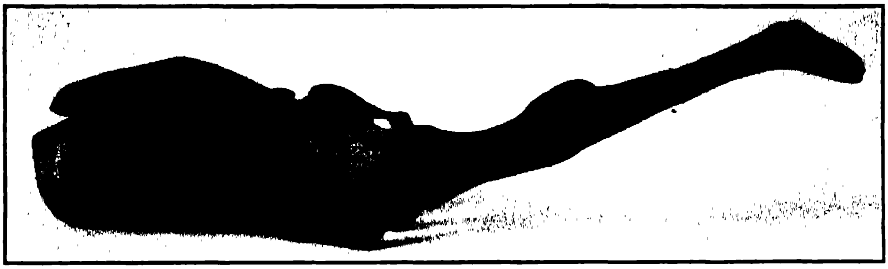
> Purple the sails, and so perfumed that
> The winds were love-sick . . . .
>   From the barge
> A strange invisible perfume hits the sense
> Of the adjacent wharfs.

Kyphi was the most celebrated of Egyptian perfumes, for the making of which several recipes have been discovered. Honey, wine, cyprus, myrrh, saffron, dock and juniper are among the sixteen ingredients given in the recipe handed down by Plutarch, of which he writes: "Its aromatic substances lull to sleep, allay anxieties, and brighten the dreams. It is made of things that delight most in the night and exhibits its virtues by night." In addition to furnishing an agreeable odor to the body and clothes, Kyphi was burned in the house to perfume the air, and was used as a medicine.

Cosmetics were employed lavishly by Egyptian women, who deemed it essential to anoint their eyelids each day with an unguent. Eyebrows were darkened with eye-paint that varied according to the seasons of the year. Cheeks and lips were rouged with red ochre, and among the richer classes both finger and toe nails were stained with henna juice to give a reddish yellow appearance. Even after death the faces of women of high rank were colored and their eyelids and eyebrows were darkened with antimony. Another beauty preparation, used by a queen of the third dynasty, was to benefit the hair, the prescription for which was contained in the Ebers Papyrus and consisted of equal parts of the heel of an Abyssinian greyhound, of date blossoms, and of asses' hoofs, boiled in oil. Perfumed oil was poured over the hair before it was combed and the coiffure arranged.

The Arabs carried on a heavy trade in perfumes, spices and aromatic oils, and they too used perfumes extravagantly. A recipe for a marvelous pie, described by Abd-El-Lateef, is as follows:

> Thirty pounds of fine flour are kneaded with 5½ pounds of oil of sesame and divided into two equal portions. Upon one place three lambs stuffed with meat, fried with oil of sesame and ground pistachio nuts, and various hot aromatics, as pepper, ginger, cinnamon, mastic, coriander seed, cumin seed, cardamons, and nutmeg. These are to be sprinkled with Rose-water infused with musk, and upon the lambs



AN EGYPTIAN TOILET BOX MADE OF WOOD, IN USE ABOUT 1500 B. C.
(In the University of Pennsylvania Museum.)

> are to be placed 20 fowls, 20 chickens, and 50 smaller birds, some of which are to be baked and stuffed with eggs, and some with meat, and some fried in the juice of sour grapes or limes. A number of small meat pies are then to be added and others filled with sugar and sweetmeats. The whole is then to be piled up into a dome, and rose-water infused with musk and aloeswood sprinkled over it. Then the other half of the pastry is to be placed over the top and the pie closed and baked, after which it must again be sprinkled with rose-water infused with musk before it is eaten.

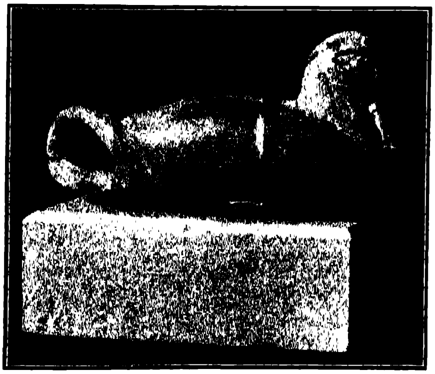
The Greeks were as lavish in the use of perfumes as were the Egyptians. Their use was thought to have originated with the gods, and Greek mythology contains many references to the gods who were enchanted by delightful odors. However, the Greeks quickly adopted this luxury for their own, using it also in their foods and wines, for which roses and violets were preferred. At banquets, to ward off the effects of the wine, the guests anointed their heads with unguents made from roses, apples, iris or spikenard. Perfumes were disseminated throughout the banquet hall, and one interesting method is quoted by C. J. S. Thompson[3] in which doves were used:

He slipped four doves, whose wings were saturate
With scents, all different in kind—these doves,
Wheeling in circles round, let fall upon us
A shower of sweet perfumery, drenching, bathing,
Both clothes and furniture and lordlings all.
I deprecate your envy when I add,
That on myself fell floods of violet odours.

The Greeks used chests of perfumed woods to store their clothing, and the most fashionable people used a special scent for each part of their body. A bath of this kind is described by Antiphanes:

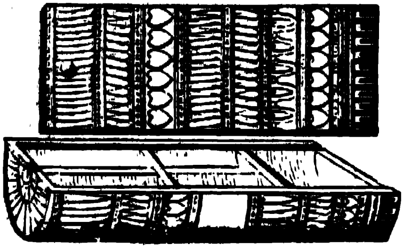
In a large gilded tub he steeps his feet
And legs in rich Egyptian unguents,
His jaws and breasts he rubs with thick palm oil,
And both his arms with extract sweet of mint,
His eyebrows and his hair with marjoram,
His knees and neck with essence of ground-thyme.

The use of perfumes was carried to such excess in Athens that a law prohibiting the sale of fragrant oils to the



AN IVORY TOILET BOX USED BY EGYPTIAN WOMEN ABOUT 3400 B. C.
(In the University of Pennsylvania Museum.)

[3] C. J. S. Thompson, "The Mystery and Lure of Perfume." Philadelphia, 1927.



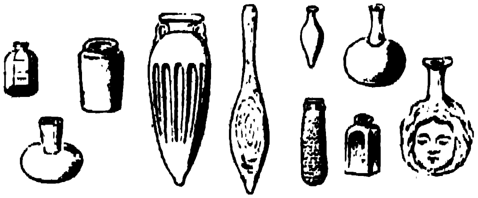
AN EGYPTIAN OINTMENT BOX WITH COMPARTMENTS
(After Rimmel.)

men of the city was passed. Nevertheless their fondness for this form of luxury persisted, and nearly two hundred years later Socrates deplored the custom by writing:

> No man is ever anointed with perfume for the sake of men, and as to women, how can they want perfume in their husbands when they themselves are redolent of it? If a slave and a freeman be anointed with perfume, they both smell alike in a moment, but those smells which are derived from free-labours require both virtuous habits and a good deal of time, if they are to be agreeable and in character with a freeman.

In spite of Socrates' antipathy to perfumes it has been recorded that one of his pupils turned perfumer, got into debt and tried to borrow money on the strength of his business.

The fashion of anointing the head at banquets is said to have arisen from the idea that the heating effects of the wine could be better borne if the head were wet. An unpleasant result of this custom, however, is mentioned by Aristotle, who attributed the frequent occurrence of gray hair to the drying nature of the spices used in the unguents.



PERFUME BOTTLES USED BY THE ROMANS
(After Rimmel.)

Among Romans the passion for perfumes was unbridled. After the conquest of Egypt, India and Arabia, enormous supplies of perfumes were obtained from them in addition to those secured from Italy and Gaul. These they used profusely in their baths, their bedrooms and their beds. The Romans, like the Greeks, had perfumes for different parts of the body, and each man, woman and child perfumed himself on leaving his bed, after the bath, and after meals. Clothing was saturated with essences, and aromatic spices were burned day and night. The trade of perfumers and unguentarii made rapid progress, and the vegetable and animal and mineral kingdoms were searched far and wide so that oils, pomades, balms, pastes, powders, cosmetics and aromatic substances could be found.

Pliny wrote:

> I can not exactly say at what period the use of unguents first found its way to Rome. It is a well-known fact, that when King Antiochus and Asia were subdued, an edict was published in the year of the City 565, in the censorship of P. Licinius Crassus and L. Julius Caesar, forbidding any one to sell exotics; for by that name unguents were then called. But, in the name of Hercules! at the present day, there are some persons who even go so far as to put them in their drink, and the bitterness produced is prized to a high degree, in order that by their lavishness on these odours they may thus gratify the senses of two parts of the body at the same moment. It is a well-known historical fact, that L. Plotius, the brother of L. Plancus, who was twice consul and censor, after being proscribed by the Triumvirs, was betrayed in his place of concealment at Salernum by the smell of his unguents, a disgrace which more than outweighed all the guilt attending his proscription. For who is there that can be of opinion that such men as this do not richly deserve to come to a violent end?

Discussing the kinds of unguents used by the Romans, Pliny said:

> And yet, even here, there are some points of difference that deserve to be remarked. We read in the works of Cicero, that those unguents which smell of the earth are preferable to those which smell of saffron; being a

> proof, that even in a matter which most strikingly bespeaks our state of extreme corruptness, it is thought as well to temper the vice by a little show of austerity. There are some persons too who look more particularly for consistency in their unguents, to which they accordingly give the name of "spissum"; thus showing that they love not only to be sprinkled, but even to be plastered over, with unguents. We have known the very soles even of the feet to be sprinkled with perfumes; a refinement which was taught, it is said, by M. Otho to the Emperor Nero. How, I should like to know, could a perfume be at all perceptible, or, indeed, productive of any kind of pleasure, when placed on that part of the body? We have heard also of a private person giving orders for the walls of the bath-room to be sprinkled with unguents, while the Emperor Caius had the same thing done to his sitting-bath: that this, too, might not be looked upon as the peculiar privilege of a prince, it was afterwards done by one of the slaves that belonged to Nero.

At one of his famous festivals Nero is said to have spent four million sesterces, or about $200,000, for roses and perfumes, and for the funeral of Poppæa he used more perfumes and incense than could be produced in a whole year in Arabia, which at that time was their chief source of supply.

To conserve the supply of fragrant materials for religious use, an attempt was made to curtail the use of perfumery under the Consulate of Licinius Crassus by passing a law. Whether this law was strictly enforced is unknown. However, a few years later Ovid told women how to acquire a beautiful complexion, the recipe for which was given in a part of a book that still remains.

> Learn from me the art of imparting to your complexion a dazzling whiteness. Divest from its husk the barley brought by our own vessels from the Libyan fields. Take two pounds of this barley with an equal quantity of bean-flour, and mix them with ten eggs. When these have been dried in the air, have them ground and add the sixth part of a pound of hartshorn. When the whole has been reduced to a fine flour, pass it through a sieve, and complete the preparation with twelve narcissus bulbs that have been pounded in a mortar, two ounces of gum, as much Tuscan-seed, and eighteen ounces of honey. Every woman who spreads this paste on her face will render it smoother and more brilliant than her mirror.

In another work, Ovid's advice was:

> Rouge a pale cheek, a red one powder,
> Each maiden knows that art's allowed her.

He, however, added the caution:

> But do not let your art be seen
> Your lover must not even find
> A powder-puff behind a screen
> Or come upon you from behind
> When the cold cream is oozing down
> And moistening your dressing-gown.

A Roman dinner, at which Julius Cæsar was a guest and Mucius Lentulus Niger the host, was described by Arthur Weigall[4] as follows:

A PERFUMER'S SHOP IN MEDIEVAL TIMES
(AFTER RIMMEL.)

> The diners lay upon couches usually arranged around three sides of the table, and they ate their food with their fingers. Chaplets of flowers were placed upon their heads, cinnamon was sprinkled upon the hair, and sweet perfumes were thrown upon their bodies and sometimes even mixed with wines. During the meals the guests were entertained by the performances of dancing girls, musicians, actors, acrobats, clowns, dwarfs, or even gladiators.

The menu at this dinner was in keeping with the entertainment. It included sea-hedgehogs, oysters, mussels, sphondyli, fieldfares with asparagus, black and white sea-acorns, glycimarides, sea-nettles, becaficoes, hares, teals, peacocks, cranes, etc., etc.

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[4] Arthur Weigall, "The Life and Times of Cleopatra," New York, 1924.

THE CIVET CAT
(FROM AN EARLY AMERICAN LITHOGRAPH.)

Other countries were scarcely less lavish in their use of perfumes, as shown by numerous references to their customs. It is said that Antiochus Epiphanes, King of Syria, employed two hundred women to sprinkle spectators at games held at Daphne with perfumes from golden vessels. Alexander the Great had the floors of his apartments sprinkled with perfumes, while myrrh and other aromatic gums were burned in his halls. A sacred fire, fed with sandalwood, perfumed oils and incense, was kept burning during the Hindu marriage ceremony. The Muslims of India rubbed their faces and bodies with perfumed powders, two favorites being "Abeer," which was made of roses, aloes-wood, sandalwood, turmeric, camphor, and civet, and "Chiksa," composed of patchouli, sandalwood, mustard seed, flour, foenugreek, cyprus, kuskus, aniseed, camphor and benzoin. The bridegroom usually presented his bride with a toilet bag containing "a box to hold betel-nut for chewing, a small bottle of attar of rose, a bottle to sprinkle Rose-water, a box for spices, a box for meesu, a powder consisting of galls and vitriol for blackening the teeth (customary for married women), a box for powder to blacken the eyelids, and one for Kajul (similar to Kohl) for darkening the eyelashes, together with a comb and other toilet necessaries." Incense burners form a part of the household equipment of the Chinese. Musk is their favorite perfume and is obtained from musk-deer on their mountains. The fondness for perfumes and cosmetics in Carthage is well illustrated in Flaubert's "Salammbo" by his description of Hamilcar's visit to his perfume room, presided over by a chief of perfumes.

> Naked men were laboriously engaged kneading pulp, pressing herbs, stirring the fires, pouring oil into jars, opening and closing little oval cells excavated all around in the walls, which were so numerous that the room resembled the interior of a beehive. Myrobalans, bdellius, saffron, and violets overflowed the place, and all about were gums, powders, roots, glass phials, branches of dropwort and rose petals; the scents were stifling, in spite of the clouds

> from the storax that crackled in the centre on a brass tripod. The Chief of Perfumes, pale and very tall, like a wax torch, came forward to greet Hamilcar by crushing over his hands a roll of aromatic ointment, whilst two slaves rubbed his heels with harewort leaves.

The servant of Hamilcar's daughter "tinted with henna the inside of the hands of her mistress, touched her cheeks with vermilion, put antimony on her eyelids, and lengthened her eyebrows with a mixture of gum, musk, ebony, and crushed flies' feet." (It is interesting to note that crushed flies were recommended for the fashionable toilet in England in the sixteenth century, when Thomas Moffet wrote in his book on insects: "A Maid that cares for her beauty, and would make the circles of her eye-lids black, Emmets eggs bruised with Flies will perform that, and give them their desire.")

After the fall of the Roman Empire the use of perfumes declined, although the barbarians who invaded western Europe would have been greatly benefited by the perfumed baths that had charmed their predecessors. Perfumes were again brought to Europe by the Crusaders, but due to religious persecution experiments in perfume-making, as in science, had to be made in secret to avoid charges of witchcraft. With the coming of the Renaissance, perfume regained something of its former popularity.

For many years Italy was foremost in the art of perfumery, supplying the rest of Europe with sweet bags, perfume cakes to be thrown on fires, fragrant candles and cosmetics, scented gloves and pomanders. But when in 1533 Catharine de Medici went to France to marry the Duke of Orleans, afterward Henry II, there was in her entourage an expert Florentine perfumer named René, and also an astrologer and alchemist who was given an apartment that was connected with the queen's by a secret staircase, and who was thought to have supplied her not only with sweet essences and perfumes but with many of the poisons and potions used by her in carrying out her political intrigues. It was René, however, who revolutionized the perfume industry in France, which had been carried on up to that time in a desultory fashion, although as early as the twelfth century it was important enough to require that perfume-makers be given charters. René's shop became the rendezvous of the fashionable world. Other Italian masters were soon attracted to France by the concessions and patronage of her kings, and in a short time the country gained the supremacy that she still maintains. It became the custom for many of the higher classes to superintend the making of their own favorite perfumes, and many had still-rooms in their homes. Louis XIV was a devotee of this art, receiving his perfumer, Martial, in his private closet for this purpose. Perfume bellows were used to diffuse sweet-smelling powders through the rooms, and Cardinal Richelieu liked his rooms scented in this manner. Madame de Pompadour's yearly perfume bills mounted as high as 500,000 livres (nearly $100,000).

Under Queen Marie Antoinette the more delicate scents of the violet and rose came into use and have retained their popularity. The perfumed baths were revived in the latter part of the eighteenth century, and Madame Tallien's favorite bath was one of crushed strawberries and raspberries, after which she was rubbed with sponges soaked in perfumed milk. Perfumed gloves made their appearance in France in the sixteenth century. To make them, the perfume materials were mixed with a fatty basis and smeared on the inside of the gloves and this also served to keep the skin soft.

Napoleon was lavish in his use of perfumes. Aloes-wood and Eau de Cologne

THE MUSK DEER
(FROM AN EARLY AMERICAN LITHOGRAPH.)

were his favorites, the latter being used when washing, and poured with an unsparing hand over his neck and shoulders to the extent of sixty bottles a month. His perfume bills were enormous. Josephine, too, was inordinately fond of perfumes, but she preferred the strong-smelling essences. Her dressing room was so redolent with her favorite, musk, that Napoleon is said to have frequently objected, and repeated washings and paintings failed to extinguish the odor.

England, perhaps, never became so enthusiastically addicted to the perfume habit, her habitual restraint tending to curb any extravagance comparable to that of France and the older countries. It was France that gave England her first real taste of this luxury, when in the tenth century Hugh the Great, seeking in marriage the sister of King Athelstan, sent her gifts of perfume "the like of which had never before been seen in England." Fragrant gums and spices were first imported into England by the Guild of Pepperers, which is mentioned in the Pipe Rolls of London in 1179. They were traders or merchants who imported medicinal and other spices from the shores of the Red Sea and various western ports. There was also another group called "Spicers." In the thirteenth century, groups of traders congregated together and their stalls were often located together in the markets, a convenience for traffic and in the adjustment of prices.

The general use of perfumes in England began in the Tudor times. Rose water, however, had been used for many years for washing the hands after banquets, a custom probably partly due to the fact that forks were considered foppish until after James I's reign. Perfumed gloves were first used in England about 1550, and Queen Elizabeth was so delighted with a pair she possessed that she had herself pictured wearing them. Every country house had its still-room, and each lady of quality had her own recipe for perfumes and domestic medicines. No perfumer is recorded in London until the seventeenth or early eighteenth century. Then Charles Lilly, the famous perfumer, prepared and marketed in his shop in the Strand "snuffs and perfumes which refresh the brain in those that have too much for their quiet, and gladdens it in those who have too little to know the want of it."

Regardless of the Rev. Thomas Tuke's book published in 1616, entitled, "A Treatise against Painting and Tincturing of Men and Women: against Murther and Poysoning: Pride and Ambition: Adulterie and Witchcraft; and the Roote of all these, Disobedience to the Ministery of the Word. Whereunto is added, The Picture of a Picture, or, The Character of a Painted Woman"—regardless of this, chemists opened shops immediately afterward and sold hair-lotions, powders for the teeth, and aromatic waters such as lavender, elder-flower and rosemary. The wearing of black patches became fashionable at this time, and this fad reached such proportions that on June 7, 1650, a bill was introduced into the House of Commons (but failed of passage) to prohibit "the vice of painting, wearing black patches and immodest dress of women." It will be remembered that Samuel Pepys always spoke with pride of the black patches which were the smart feature of his wife's dress for formal occasions.

Perfuming the person as well as the clothes came into practice in England in the eighteenth century, along with carrying the handkerchief in the hand and the use of the cane. Powdering the hair was another method of adornment at this time, but in 1795 a guinea tax on each person thus embellished was responsible for a boycott on hair powder. The person continuing its use was thereafter called a "guinea pig" and became an object of mirth. In spite of their legal measures to restrain the use of these non-essentials, perfumes and cosmetics continued in fashion, and in 1828 King George IV had perfume bills amounting to £500 17s. 11d.

Perfume-makers were enriched by the discovery of America, when additional stores of sweet-smelling plants, such as the balsam of Peru, cacao, vanilla and others, became available. To the struggling pioneers who settled in America, however, these meant nothing. For many years there was not the leisure nor the money nor the transportation facilities to permit the enjoyment of such a luxury. Nevertheless, by 1832 the women were giving more thought to the enhancement of their charms if one may accept Frances Trollope's statement in her book on the "Domestic Manners of the Americans."

> The ladies have strange ways of adding to their charms. They powder themselves immoderately, face, neck and arms, with pulverized starch; the effect is indescribably disagreeable by day-light, and not very favourable at any time. They are also most unhappily partial to false hair, which they wear in surprising quantities; this is the more to be lamented, as they generally have very fine hair of their own.

The stride from this beginning has been unbroken, but recently it has developed into a pace so rapid as to be astounding. Estimates from tax returns showed an increase of $100,000,000 in the sale of perfumes and cosmetics from 1920 to 1924, and if figures were available since that time the increase would be far more startling. A recent unofficial estimate of the Department of Commerce placed the annual expenditure for cosmetics and beauty care in the United States at nearly two billion dollars.

The earliest perfumes used were the dry, resinous gums secured from fragrant trees—myrrh, frankincense, spikenard, galbanum and others. Lack of knowledge regarding spirits of wine or strong alcohol in which to dissolve the essential oil limited the early perfumes to those which could be made with a basis of olive oil or oil of Behn, and these were called unguents or ointments. Flowers gradually came into use, and by the time the Greeks came into power the iris, rose, crocus and violet were popular.

The first scent to be extracted through the process of distillation was rose water.

AN ALABASTER PERFUME VASE FOUND IN THE TOMB OF KING TUT.ANKH.AMEN.
(FROM "THE TOMB OF TUT.ANKH.AMEN" BY HOWARD CARTER AND A. C. MACE, NEW YORK, 1923.)

In 810 A.D. a tribute of 30,000 bottles of rose water was sent from the Persian province to the treasury of Bagdad, and rose water has continued to maintain its popularity through all the centuries following. About 1393 a "citizen of Paris" gave a recipe for making rose water, in a book entitled "Le Ménagier de Paris."[5]

> To make Rosewater without Lead Alembic take a barber's basin, and cover it with a kerchief spread right over the mouth in the manner of a drum, and then lay your roses on the kerchief, and above your roses set the bottom of another basin filled with hot cinders and live charcoal.
>
> To make Rosewater without either Lead Alembic or Fire take two glass basins and do as is said at the back of this page [*i.e.* above] and instead of ashes and charcoal, set it in the sun; and in the heat thereof the water will be made.
>
> The roses of Provins be the best for putting in dresses, but they must be dried and sifted through a sieve at mid-August so that the worms fall through the holes of the sieve, and after that spread it over the dresses.

Attar of roses, the first essential oil to be obtained in a pure state, was accidentally produced in Persia about 1612. Eau de Cologne, which has been popular for more than two centuries, is said to have been first manufactured in Cologne in the early part of the eighteenth century and was sold in great quantities during the Seven Years' War for the remedial qualities it was supposed to possess.

Important among the substances used in the making of perfumes are the animal scents, or so-called "fixatives"—musk, civet, ambergris and castor—all of them obnoxious if used alone. The scent of musk, which is secured from the musk deer of Siberia, Tibet and China, is so strong that it may not be shipped in the same cargo with tea, and its value is greater than its weight in gold. Ambergris, which is even more valuable than musk, is a product secured from the sperm whale. The Oriental civet cat provides the civet that is used as a perfume ingredient, while castor is secured from the beaver. These "fixatives" are combined with the delicate flower scents and furnish the base of the perfume.

Every country and climate contribute to the supply of flowers for perfume-making. Flowers are picked at the exact moment when their scent is strongest. Roses are gathered as soon as they open, carnations after three hours' exposure to the sun, jasmine immediately after sunrise, and so on. One authority states that white flowers give by far the largest majority of sweet odors. Yellow flowers are next, and red is a close follower. Blue, violet and green are far behind, with orange and the brownish tints last. Some flowers, such as lavender and wild thyme, lose their fragrance if transported, and therefore stills are set up in the fields where they grow.

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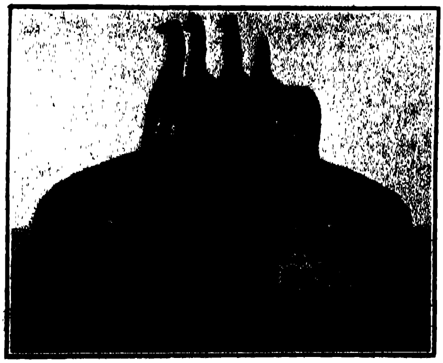
[5] Trans. by Eileen Power, New York, 1928.

Since distillation is not potent to extract fragrance from most flowers, the processes of maceration and inflowering are extensively used. In maceration, huge vats of melted beef or pork fat are used in which the fragrant parts of the flowers are mixed until the odor is exhausted, when they are drained off and fresh flowers added, and this process is repeated until the desired strength is attained. In inflowering, fresh flower petals are placed twice a day on plates of fat-coated glass, which are kept in air-tight compartments, sometimes for months, until the right strength is reached, when the pomade, as the fat is then called, is melted from the glass with warm water and treated with alcohol. It is then ready for the perfumer.

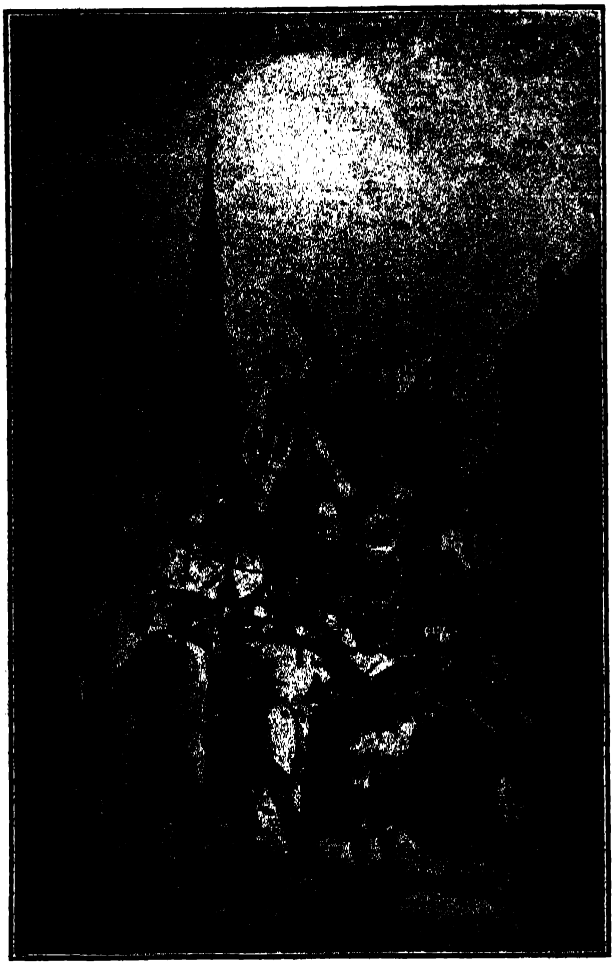
Extravagance among the ancients was not confined by any means to the scents themselves. Many were the types and designs of containers for perfumes and cosmetics in use by the luxury-loving Egyptians, Romans and Greeks. Graceful and artistic, and occasionally grotesque, are the relics that come to light on the opening of graves and as the result of archeological excavations. Little ivory and wooden toilet boxes, alabaster, onyx or glass perfume bottles, alabaster vases, ointment boxes, stone kohl jars, jars of polished hematite, serpentine and alabaster—all bear their mute testimony of the popularity of cosmetics. As many as fifty or more small, dainty phials, bottles and jars which held oils and cosmetics for the use of the dead have been found in a single tomb. Later, "pomanders" became an article of fashionable luxury. While this article doubtless was originally composed of medicinal substances as a preventive of infection, it soon developed into an exquisite article of jewelry containing favorite perfumes. The globular cases containing the pomanders were worn on a chain around the neck or as a pendant hung upon the girdle. They were made of gold or silver, and sometimes were mounted with precious stones. "The Receipt Book of John Middleton," published in 1734, gave the following recipe for a pomander:

> *"To make a Pomander*
>
> Take Benjamin, Labdanum and Storax of each an ounce. Then heat a mortar very hot and heat them all to a perfect paste adding four grains of Civet and six of musk. Then roll your paste into small beads, make holes in them and string them while they are hot.

Sometimes the cases were divided into several partitions, in each of which was placed a different perfume. A nutmeg, set in silver and decorated with stones and pearls, was occasionally used as a pomander, and oranges became popular pomanders soon after their introduction into England. Usually the center was hollowed out and filled with spices or other scents. When the case was of



A "PYXIDE" OR COVERED JAR FOR COSMETICS, USED BY THE GREEKS ABOUT 800 B. C.
(IN THE UNIVERSITY OF PENNSYLVANIA MUSEUM.)



A STROLLING PERFUME VENDER OF THE TIME OF LOUIS XV
(AFTER RIMMEL.)

silver it was perforated with holes, to let out the scent, and thus originated the present-day vinaigrette. "Casting bottles," containing a top or stoppers pierced with little holes, were used in Shakespeare's time for sprinkling perfume on the head, face and hands. In the seventeenth and eighteenth centuries, the laboratory of the monastery of Santa Maria Novella, of Florence, was famous for its scents which were placed in tiny bottles in small boxes or cases, sometimes resembling a book, the covers being ornamented in gold or color.

Selling methods, too, have traveled their devious ways down through the ages. The ruins of Herculaneum and Pompeii have yielded signs that appear to have been made of stone, or terra-cotta rilievo, and let into the pilasters at the side of the open shop-fronts. At a perfumer's shop, four men carrying a box with vases of perfume, and men laying out and perfuming a corpse, were shown as representative items of that profession. In Athens, the shops of perfumers served as meeting places for all classes of society, including statesmen, artists, philosophers, and men of fashion, who discussed affairs of state, scandal and the latest fashionable intelligence. Among the Romans, as perfumes increased in popularity, the perfumers were despised. Decent people never entered their shops without hiding their faces, and rich persons had their own perfume laboratories.

In London, the selling of perfumes and cosmetics was often combined with the selling of medicines. Quackery was one of the most flourishing of occupations there in the seventeenth century. Gaudy handbills told of miraculous remedies; nurses, landladies and a retinue of followers were hired or bribed to proclaim the skill of the notorious quacks; a "Zany" or "Merry Andrew" was employed to enact the part of fool on the stage or street to attract the attention of gullible crowds; flowery oratory rendered the credulous audiences helpless before the marvelous remedies for every imaginary ill—physical or mental. A part of the speech of one Ben Willmore will sufficiently illustrate the vaunted efficacy of their wares. Dressed in a scarlet coat trimmed lavishly with braid, wearing a cocked hat with a feather, and holding aloft a small bottle, he would call from his stage on Tower-hill:

> Gentlemen and Ladies,
>
> Behold this little vial, which contains in its narrow bounds what the whole universe cannot purchase, if sold to its true value. This admirable, this miraculous Elixir, drawn from the *hearts of Mandrakes, Phoenix Livers, Tongues of Mermaids* and distilled by contracted *Sunbeams,* has, besides the unknown virtue of curing all distempers both of mind and body, that Divine one of animating the Heart of man to that degree, that however, remiss, cold and cowardly by Nature, he shall become *Vigorous* and *Brave.*
>
> Gentlemen, if any of you present was at Death's Door, here's this, my *Divine Elixir,* will give you Life again.
>
> "This will recover whole fields of Slain,
> And all the Dead shall rise and fight again."
>
> Come, gentlemen, buy this *Coward's Comfort,* Quickly buy! What fop would be abused, mimick'd and scorn'd for fear of wounds that can be so easily cur'd. Who is it, would bear the insolence and pride of domineering great men, proud officers or magistrates? What foolish heir, undone by cheating gamesters?
>
> What Lord, would be lampooned? What poet, fear the malice of his satyrical Brother? Come, buy my Coward's Comfort, quickly buy!
>
> Here Gent, is my little Paper of Powder whose value surmounts that of *Rocks of Diamonds* and *Hills of Gold.* 'Twas this made *Venus* a goddess and given her *Apollo.*
>
> Come, buy it Ladies, you that would be fair and wear eternal Youth, and you in whom the amorous fire remains, when all the charms are fled; you that dress young and gay, that patch and paint, to fill up sometimes old furrows on your brows and set yourselves for conquest though in vain. Here's that, which will give you *Auburn Hair, White teeth, Red Lips* and *Dimples* on your cheeks. Come, buy it, all you that are past bewitching, and you'd have handsome, young and active Lovers!
>
> Come, all you City wives, that would advance your husbands to be Lord Mayors, come buy of me now *Beauty.* This will give it, though now decayed as are your shop commodities; this will retrieve your customers and vend your false and out-of-fashion wares. Cheat, lye, protest and couzen as you please, a *handsome wife* makes all a lawful gain.

In spite of the inability of cosmetics to make all women beautiful, their use has grown prodigiously in recent years, and doubtless will continue to grow so long as women are women and men are men and the wherewithal is available to pay for them.

THE CULTURE OF THE CAMPAS INDIANS OF SOUTH AMERICA

By Professor **MORRIS G. CALDWELL** and **JOHN CALHOUN**
ASHLAND COLLEGE

I. Geography, Climate, Etc.

The Campas Indians are located in east central Peru. This region comprises several thousand square miles of jungle and mountainous lands. It is bounded on the east by the Ucanali River and on the west by a line extending from Jauja, through Tarma, to Huanuco. This area extends as far north as the Pachitea River and as far south as the Mantaro River. Several rivers, which are tributaries of the Amazon, form a network throughout the entire region. The climate is tropical. The rainy season lasts during our winter months. The lowlands are covered with a dense undergrowth and impassable jungle. This vast tropical region may be legitimately called the Campas Culture Area, because the culture of these Indians is uniformly characteristic of the whole district.

It is not known how many people inhabit this vast area, but it is estimated at several thousand natives. The Campas Indians are a race of small stature, averaging about five feet two inches in height. They resemble certain tribes of North American Indians in stature, physiognomy and general physical characteristics. These people all speak the Campas dialect. There are no written records of the history of these peoples, due to the absence of written language. The customs, folkways and mores of the group are passed on to the next generation by word of mouth.

II. Material Culture

Although these native Americans appear somewhat backward and retarded in non-material culture and social organization, nevertheless, they possess a well developed material culture. Some

FIG. 1. A TYPICAL GROUP OF CAMPAS INDIANS.

of the most important material culture traits may be described as follows.

Weapons: Human weapons consist of arrows made of bamboo reed three feet long by one quarter inch in diameter, with a sharpened palmwood head approximately sixteen inches long. The arrow is feathered on the tail end. The arrows used in killing large birds are made of bamboo reed four feet long by one half inch in diameter, with a hard palmwood head ten inches long. Encircling the arrow point are four small sharpened prongs three and one half inches long. These prongs pierce the body of the wounded bird and hold it fast until the hunter arrives. Both the human and game arrow heads have notches on them. This helps the arrow to stick to the flesh into which it is fired. Arrows for stunning small birds are made from bamboo reed three feet and nine inches long by one half inch in diameter with a blunt hardwood head about two inches long. The feathers of brilliantly colored birds are much in demand for personal decoration. Arrow for deer are made from bamboo reed of usual length and thickness, with a flat bamboo head thirteen inches long by one inch in width and about a quarter of an inch thick. The head is fastened to the reed by homegrown cotton thread. The fish arrow is also made of bamboo reed, with a twenty-inch triangular palmwood head with three sets of barbs or notches on it. The bow by which the foregoing arrows are fired consists of a palmwood stick five feet long, one and a half inches wide and about one quarter of an inch thick. The bow is strung with a coarse cord made from a very tough native vine. The fish spear consists of a flat hardwood head twelve inches long. This head has a sharp point and edges. The head is fitted into the socket of a bamboo shaft six feet long and one inch in diameter. Fishing

FIG. 2. NATIVE WOMAN CARRYING YUCCA.

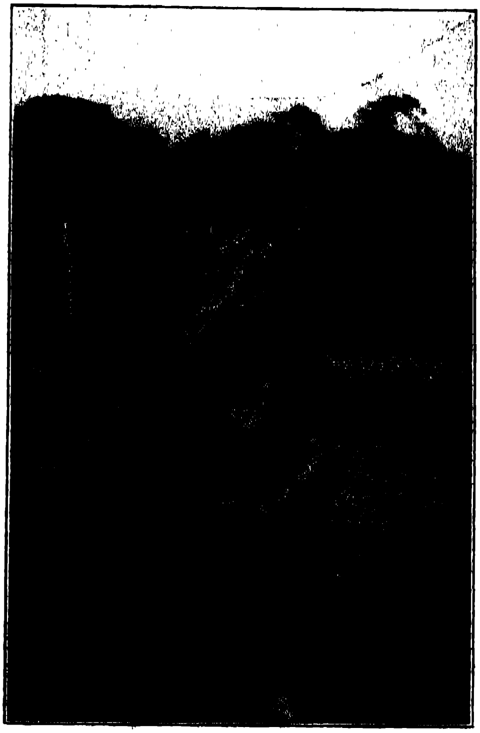


FIG. 3. A TYPICAL MOTHER.

is universally carried on from the canoes.

Hunting axe: This axe is a dull bladed instrument made of soft porous stone. The axe blade is about four inches long and four inches wide and about one inch in diameter at the thickest place. The axe head, which is a "V" shape, is set into a wooden handle two feet long and fastened there by strong cord. The axe is used as a tool and also as a weapon of war.

Due to the impassability of the jungle, water transportation on the system of rivers is the principal means of communication. Dugout canoes thirty-five feet long and five feet wide are made from the palmwood tree by means of stone axes and the use of fire. The canoe is propelled forward by means of two oars, one on each side. Each oar has a blade fifteen inches wide and three feet long and a handle three feet in length. The sides of the canoe are generally painted with designs of various kinds. Transportation is reckoned in days, so many days up the river and so many days down the river.

Pottery: Pottery jars are made of a yellow clay from the banks of the rivers in sizes ranging from one half pint to a gallon. These jars are used for carrying water, gathering berries and fruits and storing foods. They are most always decorated with dyes made from the bark and roots of a certain kind of tree. In the absence of pottery, gourds are used as containers.

Spinning, weaving and clothing: Cotton grows wild in the highlands of this region. It is picked in much the same manner as it is in the South of this country. The cotton is then spun on to a spindle, which is nine and one half inches long. On one end of the spindle is fastened a cyclindrical stone one inch in diameter, which serves as a balance wheel. The spindle is operated between the palms of the hands. When the spindle is full it looks like a big spool of thread. The cotton thread is then woven on to a triangular hand loom. The loom ranges in size from ten inches wide and twenty inches long to six feet wide and eight feet long, depending on the size of the garment to be woven. All garments are then colored by a dye made from the bark of a tree. The cushma is the principal garment worn by the natives of this region. It is a sort of a "slip-over" garment. It has slits for the neck and arms, but no sleeves. A simple slit in the garment for the neck indicates a female garment, while a "V" shape slit is for the male. These garments are often decorated with feathers and bunches of bone, seeds, nuts, toe nails of small animals, and bones of small birds and monkeys. The pancho is a top garment worn in rainy weather, also in cold weather for the Campas Indians living in the mountains. Most of the natives possess a large pouch made of cotton cloth, which is hung over one shoulder. This pouch

FIG. 4. CHIEF HUÑANCO.

contains the tinder, whistles and chewing material for the day's journey.

The women are the "beasts of burden" in this region. They transport heavy materials by means of huge carrying bags or nets which hang down the back. The weight of the load is borne by a three inch band which goes over the top of the head.

Foods: The chief food of this area is the yucca. It is a tuber-like vegetable which grows underground. It is boiled and prepared for table use in the same manner as potatoes. The native also eats the heart of the cabbage palm tree, which is cooked like cabbage and resembles it in flavor. Bananas, wild oranges and limes are the principal fruits. These people balance their diet with a variety of meats, including the monkey, deer, birds, variety of fish, all kinds of insects, worms, ants and certain snakes. The Campas Indians use fire in the preparation of their food. They kindle it by means of the bow and arrow method. The leaves of the coca are preserved and carried in a hollow section of a bamboo stick. These leaves are chewed like tobacco after they have been moistened with a little powdered lime. An intoxicating beverage is made by the old women of the group who are too old to work in the yucca fields. These old women form a circle around a big gourd jar and begin chewing on the yucca root. When their mouths are full of juice, they spit into the gourd. When the gourd is full of juice, it is put aside to ferment. In due time the mould and other extraneous material is strained off and the remainder, which is pure alcohol, is consumed. A socialized good time follows. There is much dancing and beating of the drums.

Ornaments and decorations: Strings of beads, measuring four feet in length, are made from hard seeds of certain tropical bushes and vines. These seeds are about half the size of a cranberry. They are boiled in water until soft, and then threaded on to tough cords in color designs and patterns. The black and white strings of beads are worn by the chieftains, and the red and black, or pure red are worn by the women. It is worn over the head and one shoulder. Often a string of beads may have the toe nails of a sea cow or anteater tied to it for decoration. Strands of native grass are woven together into bands or loops and worn over the head and one shoulder by the women. Rouge, made from the red bark of a certain tree, is worn on the forehead, nose, cheeks and chin by all members of the group in profusion. Bunches of brilliantly colored bird feathers are worn for decoration. The corona is a head crown made of split bamboo covered in design with highly colored cotton threads. It is decorated with one or more bird feathers.

Musical instruments: The Campas Indians have four important musical instruments: the "tom-tom" drum, the bow violin, bone whistle and the pipe whistle. The "tom-tom" is a hollow section of bamboo tree ten inches long and eight inches in diameter, covered at both ends by monkey skin. The drum is beat upon by the leg bone of a deer. The bow violin is played upon by a limber reed about two feet long. The bone whistle is the leg bone of a deer with two holes drilled through it to blow on. The pipe whistle consists of five hollow reeds tied together with native cotton cord.

III. Social Organization

The social organization of the Campas Indians is very simple, indeed. Polygamy is the order of the day. There is no limitation on the number of wives a man may possess. When a man marries a second wife, he may kill his first wife if he so desires. It is not considered a criminal offense, but simply regarded as "good taste" on the

FIG. 5. A FUNERAL PARTY.

part of the male. There is no such thing as private property, outside of clothing and a few personal effects. The ownership of the land is vested in the tribe. The Campas Culture Area is not a homogeneous entity politically, but rather a multiplicity of groups, each under the leadership of a chieftain.

IV. RELIGION

The Campas Indians are sun worshippers. They are desolate when night comes because their god has disappeared. They practice no religious rites or ceremonies and have no medicine men. They believe in life after death, but an existence, moreover, in which the soul roams constantly through the jungle, seeking rest and finding none. The adult person at death becomes an evil spirit. If he has a house or other property it is burned immediately, so that the evil spirit can not come back to haunt the place. Fire is supposed to chase away evil spirits, so a native always starts a fire wherever he sleeps at night. The spirit of a child after death is not evil, but comes back into the home and so the mother must make provision for it. If she goes canoeing on the river, she must tie a tiny raft behind her boat for the child's spirit to ride in. If the mother goes into the forest and finds a large fallen tree, a stick must be laid against each side of the tree for the spirit of the child to cross over.

When a member of the group dies, the corpse is wrapped in cotton cloth from head to foot and tied to a long pole for convenience in carrying to the funeral. The manner in which the dead are disposed of is not known. The natives are determined to keep this a secret of their race. Any white man who attempts to pry into this mystery is endangering his own life. The accompanying picture is a snapshot of a funeral party proceeding through the jungle, taken without the knowledge of the natives.

SINO-AMERICAN POINTS OF CONTACT

By Dr. BERTHOLD LAUFER

CURATOR OF ANTHROPOLOGY, FIELD MUSEUM OF NATURAL HISTORY, CHICAGO

ABOUT a hundred and fifty years ago Americans first came in direct contact with Chinese when the American ship *Empress of China,* sailing from Boston and rounding the Cape of Good Hope, cast anchor in the harbor of Canton. This occurred in the year 1784, under the reign of the great Emperor Ch'ien Lung, who was a contemporary of George Washington. Thus Americans were late arrivals—in fact, the last of foreign peoples to enter into commercial and political relations with China. Europeans, first the Portuguese, then the Spaniards, Hollanders, British, and French, had preceded them by several centuries. It is no empty saying that from the first days of Sino-American intercourse the two great countries have been linked by bonds of sympathy which have not existed and do not exist between China and any European power. These bonds of sympathy and friendship have been strengthened from year to year, as witnessed particularly by the ever-increasing number of Chinese students and scholars annually flocking to our universities athirst for knowledge.

What, then, have Americans and Chinese in common? I think, a goodly number of very fine traits. First, the spirit of democracy, which has pervaded China for more than two thousand years, ever since the First Emperor Ch'in Shi smashed the old feudal system. The principle of government for the benefit of the people certainly is American, but it is equally Chinese and goes back to the fourth century B.C., when Meng-tse (Mencius), the most gifted of Confucius's disciples proclaimed the doctrine, "The people are the most important in a nation, and the sovereign is the least important of all." Second, the spirit of religious tolerance. I know of no more tolerant nation than the Chinese. Third, the lack of a caste system and lack of a hereditary nobility. China was always guided and governed by an aristocracy of intellect, not of birth; the old system of free competition by civil service examinations recruited the best talent from all ranks of society. Fourth, Americans and Chinese do not suffer from the obsession of that great evil, the race superiority complex; they are averse to armed force; they are friends of peace, and are animated by a deep sense of justice and fair play toward all, regardless of race, color or creed. Fifth, and this is the greatest asset that the two nations have in common, they have an unbounded, almost religiously fanatic, faith in the power of education and knowledge as the best guarantors of progress, as the best possible safeguards of the permanence of their social structure and institutions. With this capital of a common historical tradition and mentality—democracy, tolerance, equality, justice and education—we are well prepared to stand the test and storms of the time.

Aside from these ideals, there are culture elements inherent in the two civilizations that establish a common basis for a harmonious social life and sympathetic fellowship among representatives of the two nations. In reflecting on cultural similarities between Americans and Chinese, it is advisable to proceed from realities and direct observations. A white man who is in a good state of health is able to live in China in a house of Chinese style, in a purely Chinese surrounding, on Chinese food, in every fashion exactly like a Chinaman, not only for years, but a lifetime, without suffering impairment or injury to his health. Chinese houses are very much like our own; their plan of arrangement comes very close to that of the ancient Roman house. Rooms are airy, spacious and well-ventilated, and comfortably stocked with tables, chairs, armchairs, settles and sofas. There is no other nation in the world whose house furniture offers so complete and striking a coincidence with our own. In fact, it is one of the amazing points of culture history that of all nations of Asia the Chinese is the only one that takes its meals seated on chairs around a table, in the same manner as we do. This custom was acquired by the Chinese only in comparatively late historical times. The ancient Chinese, down to the epoch of the two Han dynasties, used to squat at meal times on mats spread over the ground, in the same way as it is still customary with the Japanese and the peoples of India. The remarkable step leading to the use of raised chairs and high tables was taken in the period between the Han and T'ang dynasties, as a sequel of many foreign influences that came from Central Asia at that time, and speaks volumes in favor of Chinese adaptability and readiness to adopt foreign institutions. The Japanese, with all their temperamental changeability, still adhere to the old primitive custom of sitting cross-legged on the mats covering the floors of their rooms; and while an American, for curiosity's or experience sake, may enjoy living in a Japanese home for a few days or weeks, he will never acquire the Japanese mode of sitting, which is a source of physical discomfort to us.

The objection may be interposed that many travelers and adventurers in almost all parts of the world have conformed to the life of the natives whom they set out to explore. Such examples indeed are numerous. Any normal individual of good physique and temperate habits is able to live wherever other human beings of whatever race can exist, whether they be Eskimo, American Indians, South Sea Islanders, Pygmies or Negroes, Berbers or Beduins; but such adventures are usually transient, and the explorer will always be glad, once his task is accomplished, to return into the harbor of "civilization." Speaking of myself, it fell to my lot to live for many months among such primitive folks as the Gilyak and Ainu of Saghalin Island, the Golde and Tungusian tribes of the Amur region, sharing their huts or spending the night in the open, sleeping on a bearskin, living like them on salmon and game, even amid smallpox and trachoma epidemics, without any harm to my health, save a temporary discomfort from parasitic insects. I could not, however, have stood this sort of life for a number of years, and while I enjoyed studying these tribes and gathering data concerning their daily life, languages, folk-lore and religion, I can not say that I felt at home with them, at least not so intimately as I do feel at home with the Chinese. It was also my good fortune to spend a year and a half among the Tibetans, both the nomads and the agriculturists, just living like one of them; and while the Tibetans have my unstinted sympathy, the time I should be willing to dwell in their midst will always be one of restricted duration. The lesson to be retained, therefore, is that a robust man with a definite object in mind may live anywhere without hazard of life and welfare within a limited period, whereas no such time limit is attached for us to China. Again, it can not be doubted that many white individuals have settled among Indians, Eskimo and other primitive peoples, taking native women as their wives, even adopting native speech, clothing and habits, and thus ending their days. Examples of this kind are not typical, however, and such individuals have usually been fugitives, castaways, tramps, derelicts or sailors cast adrift.

In order to settle among the Chinese, no foreigner need feel anxiety about his health, at least no more than if he stayed at home, nor does he require the explorer's physical fiber. China beckons to the man of culture, and the more cultured he is, the more welcome and the happier he will be there, since the Chinese are highly cultured, well-bred and well-mannered people. Even most Chinese farmers and laborers are gentlemen, and from many of them many a so-called gentleman in our midst could learn many a useful lesson in good manners or etiquette.

One of the most remarkable inventions ever made by the Chinese is the chopsticks, "the nimble ones," as they are called in Chinese, the invention of which goes back to the days of the Chou dynasty. Chopsticks are not only characteristically Chinese but also set the Chinese people clearly off from other nations of Asia that are still in the habit of taking food to their mouth with their fingers, which is even done by so highly civilized people as those of India. Annamese, Koreans, Japanese and other peoples who came under the spell of Chinese civilization adopted from the latter the use of chopsticks. It is self-evident that these make for good table-manners, which are the first criterion of a civilized individual; and whatever opinions we may hold on the Confucian system of ethics, it is undeniable that it has at least brought about the one good effect to transform the majority of the people into a body of highly decent, respectable and well-bred men. The sanctity of the home and the purity of family life belong to the greatest achievements of Confucian social ethics. For all these reasons, official and personal intercourse of Americans with Chinese is easy and a source of pleasure. Their sense of humor, their delight in story-telling, their conversational gifts and oratorical power are other qualities that will not fail to make a strong appeal and endear them to us the closer we get acquainted. At Chinese parties there is less formality and conventionality than in our country.

Their eminent faculty of assimilating and absorbing foreign racial elements has struck many observers. In fact, the Chinese no more than any other nation represent a pure race. The northern Chinese have a strong admixture of Tungusian, Mongol and Turkish blood; the southerners have to a great extent intermarried with the aboriginal tribes which preceded the Chinese as owners of the country. The question of intermarriages of Chinese and whites is naturally a delicate one, and it would be futile to generalize on so vital and large a problem; but if limited personal experience and observation may count a little, I may say that many happy marriages of Europeans and Americans with Chinese women have come within my notice. There is no gulf separating the two races, and there are no obstacles of a racial or cultural character in the way of such unions. The offspring of American fathers and Chinese mothers belongs to the best citizenry of China, and commanding the two languages as they do, they make the best liaison officers to maintain and strengthen the bonds between East and West. Many of these Eurasians are splendid fellows, and I have found in them the most willing and enthusiastic helpmates in scientific investigations.

As an analyst of human nature I should be the last to deny that there are psychological differences between Chinese and ourselves. These, however, do not spring from a basically divergent mentality or psyche but are merely the upshot of a distinct set of traditions and education based upon the latter. As the grasp of ancient traditions upon their minds will gradually loosen and as the best in our institutions and inventions will be adopted (I advisedly shun the ambiguous and much misused word "progress"), these small divergences will gradually disappear or be reduced to a minimum. The abandonment of foot-binding and opium-smoking may be cited as relevant instances. The student of anthropology who has learned to fathom and to understand the customs and usages of every people knows only too well that the Chinese are not different from other peoples but are just human and humane. There is no custom in China that in one or another form would not appear among other peoples or even among ourselves. The Chinese worshiped their ancestors and to a large extent still do so; they are justly proud of their ancestors, and in their modesty attribute their own good luck and success to their ancestors' virtues and beneficent influence. We, with our pride in ancestors and with our passion for genealogical quests, are no less ancestor worshipers; our "worship" has merely assumed a different form.

The following simple story will illustrate this point and is also instructive in teaching that East and West, with a little good-will and thoughtfulness, are able to understand each other. An American sailor and a Chinese youth met at a cemetery near Shanghai. The sailor carried a wreath of flowers, ready to place it on the grave of a comrade who had perished in a typhoon in the China Sea. The Chinese boy carried a bowl of rice with a pair of chopsticks laid across it. The two engaged in a confabulation, and the sailor remarked laughingly, "John, what is the big idea of taking a bowl of rice to a cemetery?" And John replied, "I am going to put this bowl of rice on the grave of my ancestors as an offering to them." "Good work!" retorted the American, "And do you really believe that your ancestor will descend from heaven to eat your rice?" And John came back with this repartee, "Sure, if your ancestor can come down to smell your flowers, mine may come down as well to eat my rice!"

WILL BIRTH CONTROL LEAD TO EXTINCTION?

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ANY one who has had much contact with the active partisans of the birth control movement can not fail to be impressed with their intelligence, moral courage and sincere concern for the welfare of humanity. The movement is championed by teachers, writers, social workers, ministers, even bishops and reverend deans—all sorts of aggressively good people who are firmly convinced that birth control will afford a potent remedy for many of our worst social and economic ills. One feels almost guilty in saying anything calculated to dampen the ardor of these zealous humanitarians. But, being possessed of a scientific conscience, I can not refrain from making some comments on a possible effect of birth control which, obvious though the possibility is, has seldom received adequate consideration. If a remedy relieves the patient only to kill him off later unless it is wisely employed, we should obviously pay some heed to the avoidance of its dangers.

That the practice of birth control would confer an inestimable boon upon many ailing and overburdened mothers admits of no doubt. That it would bring the means of securing a higher standard of welfare to the peoples of such grossly overpopulated countries as China, India and Japan is equally obvious. On the other hand, birth control is largely responsible for the very low birth rate of the more intelligent and educated classes of both Europe and America. In several countries at least, the people whose position or achievements indicate that they possess a superior inheritance of brains are not producing a sufficient number of children to perpetuate their stock. Whatever its benefits may have been, birth control must bear the responsibility for the evils of the differential birth rate which have aroused the doleful lamentations of the eugenists.

That the race is at present tending to breed out its brains is possibly only a temporary evil which may be remedied by encouraging birth control in the lower hereditary classes. One of the favorite arguments of the advocates of birth control is that the reduction of the birth rate among people of inferior heredity affords the most feasible method of eugenic reform. There can be no doubt that the quality of the race would be improved if fewer children were produced by the masses of stupid people who are now most given to unrestrained fecundity. And there is probably something in the contention that the reduction of the birth rate in this class would automatically bring about a more rapid multiplication of better endowed individuals.

In bringing the propagation of human beings under voluntary control we should be alive to the dangers as well as the possible benefits of this change. Few people realize the momentous possibilities both for good and for evil which this change involves. The decline in the birth rate, which is to a large extent due to birth control, has already been fraught with tremendous consequences to the population growth of both Europe and America. At times, and in some countries, the death rate has fallen more rapidly than the birth rate, so that the net rate of population growth has not fallen off, but this condition is far from typical. Obviously the death rate can not fall indefinitely, while the birth rate can. The death rate will decline more slowly as people come to approach the maximum natural span of life. Rates of increase have for some time been growing slower. Year after year the vital statistics of most civilized countries record a lower birth rate than ever before. Since the great war the decline has continued at an accelerated pace. Will the birth rate continue to fall? There seems to be every indication that it will. In fact, several countries of Europe are threatened with an actual loss of numbers in the not distant future. For some time France has maintained a nearly stationary population only through the immigration of relatively prolific aliens from beyond her borders. The latest report from Germany (1928) gives a birth rate of only 18.6 per 1,000, a figure lower than the birth rate which has long prevailed in France.

One circumstance which has prevented us from realizing how nearly inadequate are the birth rates prevailing in many countries is that the age composition of the inhabitants is especially favorable for a high birth rate and a low death rate. Where the birth rate has been falling the proportion of children is relatively low and the proportion of people in the reproductive period of life is apt to be large. A small number of infants and very young children in a population tends also to reduce the general death rate. A population which includes a high percentage of people of adolescent and middle age may show many more births than deaths, while at the same time the reproductive rate is not high enough to secure its continued propagation. In time a population tends to outgrow the anomalies of its age composition. Because births outnumber deaths it does not follow that a population will go on increasing.

This fact, which has generally been overlooked even by specialists in vital statistics, has been brought out very clearly in a recent book by Kuczynski on "The Balance of Births and Deaths." Kuczynski has studied the stabilized rates of increase of the countries of Northern and Western Europe and finds that, were it not for their peculiarly favorable age composition, the peoples of most of these countries would be actually diminishing in numbers. At the birth and death rates prevailing from 1922 to 1925 in France 1000 women would produce only 937 women who would live long enough to replace them. Measured in the same way the reproductive rate of England in 1927 was about 910. In the same year Germany had a reproductive rate of only 830—which will be good news to the French. The stabilized rate of natural increase in the birth registration area of the United States was estimated by Dublin and Lotka to have been only about 5.5 per 1,000 in 1920, and a more recent study by the same writers has shown that by 1928 it had fallen as low as 1.7 per 1,000. Even with no further changes in the fertility or mortality of different age groups the population of the United States would gradually settle down to a nearly stationary condition.

These striking revelations of recent students of vital statistics indicate that, in the near future at least, the specter of overpopulation need not alarm us. Some of the overcrowded countries of Europe might well spare a few millions of their inhabitants and be all the better for the loss. Were it possible to do so, it would be desirable to keep the population of every country at that level which is most conducive to the welfare of the people as a whole. Some countries have altogether too many people for their own good, and others perhaps have too few. That the decline of the birth rate will be halted somewhere near the population optimum can not be assumed. To what lengths the reduction of the birth rate may go until, if ever, it comes to a natural stopping place we have at present no means of knowing. It is true that populations in the past have been subject to a sort of automatic self-regulation of numbers. Among human beings, as among the lower animals, the reproductive instincts could always be relied upon to furnish a birth supply more than adequate to perpetuate the species. However the ranks of humanity might be decimated through war, pestilence or famine, human fecundity has always proven sufficient to make good the losses. Population has been compared with an elastic spring ever ready to expand upon the release of pressure. But whether this self-regulation of numbers would occur in a people among whom procreation had come to be an entirely free will offering to posterity is open to some doubt.

Let us imagine a country whose people have all become acquainted with easy and effective methods of checking the birth supply. Let us suppose that the high standards of living in this country are insured by the restriction of immigration. How far, under the circumstances, would the population in such a country tend to decrease? Are there counteracting forces powerful enough at any point to change a decrease in numbers into an increase? It may be admitted that compensating factors exist, but have we sufficient assurance that they will be able to stay the continued decrease in numbers? Can we rely upon the desire for children either for their own sake or as an economic asset later in life, considerations of race welfare, or any other motive as affording incentives which will cause the rank and file of human beings to undergo the sacrifices required for perpetuating the race? Here is the true riddle of the sphinx, for the fate of the race depends upon its proper answer.

If the sexual propensities can be easily dissociated at will from their connection with reproduction the chief factor which causes population to increase after it has sustained a loss will no longer be operative. The danger of birth control is that it strikes at the root of Nature's method of regulating numbers. Possibly other factors which induce people to have children may still suffice, but if one can believe it in the light of recent developments he must indeed be an optimist.

The parental instincts of many people are as well satisfied by one or two children as by half a dozen. There are not a few married couples who prefer to have none. It may be very desirable to have children born only when they are wanted, but one can not help wondering what under these conditions might happen to the human species. The habit of counting the cost will doubtless grow as there comes to be an increased realization that, in our modern life, rearing children involves many sacrifices for people of moderate incomes. Where the pinch of poverty is more acutely felt, people will be only too willing to avoid these sacrifices in the effort to maintain a decent standard of living.

One may be reasonably sure that the birth rate will continue to fall as knowledge of preventive methods becomes more widely diffused among the lower social classes. In Europe there has been a strong movement in this direction since the great war. In several districts of Stockholm and in some parts of Germany this extension has proceeded so far as practically to obliterate the differences in fecundity between the upper and the lower social strata. Knowledge of contraceptive methods is bound to increase, and it is futile to attempt to check it by adverse legislation. In most countries the rank and file of the population, especially in rural districts, are still in an unsophisticated stage. Any one who reads the harrowing letters in such books as Mrs. Sanger's "Motherhood in Bondage" or Mrs. Stopes' "The First Hundred Thousand" will realize the extent of popular ignorance on this subject, and the eagerness with which knowledge is sought. An interesting picture of the situation is portrayed in the Lynds' book entitled "Middletown." In discussing the attitudes toward voluntary parenthood the authors state that "all of the 27 women of the business class who gave information on this point used or believed in the use of some form of birth control, and took it for granted. Of the 75 wives of workers from whom information was secured on this subject only 34 said that they used any means of birth control; of these 12 were "careful," 2 used primitive practices, and only 20 used artificial means that might be considered moderately scientific. Of the 34 not using any means of birth control 15 vaguely approved, 15 definitely disapproved, 4 were ignorant of all contraceptives except such as their husbands were unwilling to use, and 9 were eager for some means of control but totally ignorant of any."

This picture is probably as typical of the ignorance and confusion among the working classes as Middletown is typical of a mid-western town. To judge from the number of babies in this town who were not wanted, at least before they arrived, a wider diffusion of contraceptive knowledge would depress the general birth rate to a considerably lower level.

Another factor to be reckoned with is improvements in technique. Most of the contraceptive methods now employed are by no means infallible and suffer from drawbacks which prevent their use by the poorer inhabitants of overcrowded quarters. There is a stratum of ignorant and shiftless poor who apparently care little whether babies come or not. On the other hand, there are countless overburdened mothers who would gladly employ any safe and effective means of contraception within their reach. Should experimentation result, as it promises to do, in the discovery of more effective methods adapted for employment under the most unfavorable conditions of life it might eventually lead to a marked reduction in the fecundity of a large class which is now little affected by the birth control movement.

It is a significant fact that those countries, in which the decline of the birth rate has filtered down to the proletariat, not only have a very low general birth rate, but owe their present surplus of births over deaths largely to the favorable age composition of their inhabitants. For some of these countries an actual loss of population would confer an immediate benefit. The economic advantages resulting from this loss would naturally have the effect of enticing immigrants from surrounding areas. These countries may succeed in protecting their standards by the exclusion of immigrants, but the ability to do this implies the strength necessary to enforce their restrictions. Thinly populated Australia without the protection of Great Britain might not be suffered to remain a white man's country in face of the teeming millions of Asia who are seeking room for expansion. A weak country can succeed in keeping its territory for its own people only through the protective arm of other countries. If the protectors should become afflicted by the same weakness the position of all of them becomes insecure.

Without presuming to forecast the future, one may point out the possibility that the reduction of the birth rate in the nations under Western civilization may fall so low as to cause them to lose their supremacy in world affairs and to be invaded by peoples from other parts of the globe. The more immediate danger to the nations of Northern and Western Europe, however, lies not in forcible invasion, but in a peaceful influx of immigrants who will be welcomed as laborers. In many of the northern and eastern parts of the United States the older American stock is dying out and is being replaced by immigrant peoples who were wanted for their cheap labor. The process of replacement may or may not be harmful depending upon the inherent worth and civilization of the incoming stocks. The ancient Greeks and Romans drew in alien peoples, reduced their own birth rate, and disappeared. The extent to which birth control has been responsible for the extinction of the stocks which have built up great empires in the past can only be surmised. The practice was certainly prevalent enough in ancient times; but for the lack of adequate documents its history as a cause of extinction will probably never be written. As to its future functioning in world history we shall doubtless have abundant information.

One of the greatest problems facing civilized mankind is how to secure the undeniable economic, humanitarian and eugenic benefits of birth control and at the same time escape from its very real dangers. In taking over the regulation of the birth supply humanity has assumed a very great responsibility. One meets with little manifestation of concern over this responsibility in the typical birth control propaganda of the day. We are seldom reminded that the misuse of birth control has done a tremendous amount of damage and promises to do much more. The birth control movement arose out of the desire to relieve the overburdened mothers among the wage earning classes, and it is still motivated largely by the humanitarian aims of its early protagonists. These are worthy aims, but there is great need for the spread of enlightenment upon the larger aspects of the subject. The problems created by the growing practice of birth control are far more serious than is commonly realized. They will not be solved by the easy method of *laissez faire,* nor by fulminations against the wickedness of contraception. They may prove too much for us to cope with, and then Nature will deal with us as she does with species which fail to adjust themselves to changed conditions of life.

SOCIAL PSYCHOLOGY AND SOCIAL REFORM

By Professor KIMBALL YOUNG
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SOCIAL SCIENCE AND THE DOCTRINE OF PROGRESS

THE wish to improve or reform social conditions seems deeply ingrained in Anglo-American culture. The theory of life to which we are exposed early and late is one of material progress and continuous moral improvement. The Christian religion with its doctrine of salvation, the modern applied natural science with its omnipresent effects upon our material culture. and the dogma of consciously controlled social progress have profoundly affected us. It is almost inevitable for people to ask, "What is to be done about our social ills?" If the teacher or writer merely answers, "I do not know," or worse still, confesses no interest in reform, he is pretty sure to be put down, at least secretly, either as a knave or a fool.

Social science is not unlike natural science in its efforts to attain objectivity. It essays to be as impersonal and rational as possible in treating its data. It aims above all else to neglect none of the factors, although in social phenomena these factors are overwhelmingly complex. Social psychology is in a peculiarly difficult position. It touches all the social sciences in its effort to throw light on the behavior mechanisms of people in the various dimensions of group life. It has close bearing on the special social sciences,—history, economics, politics, sociology and anthropology.

Among the methods of science every one recognizes two levels of work: first, what may be called field description or observation, and secondly, experimentation. Where the data can successfully be stripped of interfering concrete realities, as in physics and chemistry, and to some extent in biology, laboratory experimentation, with its careful and verifiable controls, may be carried on. In the social sciences, and we include much of psychology here, the data are so complex that for the present we are compelled to use description and observation. So far as the historical dimensions of the social data are concerned, we are confined largely to qualitative descriptions and the best possible use of careful observation. In much of our work, however, considerable improvement in technique has resulted from the application of the statistics of probability in analyzing personal and group behavior.[1] Actually the social sciences, including social psychology, are in the early stages of the description and observation of their data. As all science aims to eventuate in generalizations, called hypotheses and laws, so the social sciences hope ultimately to arrive at some generalizations from their data. The natural sciences are far in advance of the social sciences in this respect although recent developments have put a new cast to their generalizations once thought more or less fixed and final.[2] One of the principal handicaps in the social sciences has been their inability to free themselves from what Comte called the metaphysical stage of development. Up to the present, most, if not all, generalizations, which have been made in most social sciences, rest upon philosophical deductions and rationalizations of contemporary cultures rather than upon descriptions and observation, to say nothing of experimentation.

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[1] *Cf.* K. Young, "Measurement of Social and Personal Traits," *Publications of American Sociological Society,* 1927, Vol. XXI, pp. 92–105, (also found in *Journal of Abnormal and Social Psychology,* 1928, Vol. xx, pp. 420–42) for a discussion of the problems of historical and statistical treatment of certain socio-psychological data. See also W. I. and D. S. Thomas, "The Child in America," 1929, chap. xiii; C. O. Lundberg, "Social Research," 1929; S. A. Rice (editor) "Methods in Social Science," 1930; and S. A. Rice (editor) "Statistics in Social Studies," 1930.

[2] Note the development in physics of theories of relativity and quanta.

Because of this lack of satisfactory generalization, if no other, the cautious social scientist refrains from offering advice on "What to do" about personal and social matters. He is more interested in the development of techniques for description, observation and, if possible, experimentation, than he is in offering gratuitous and usually fallacious programs for the improvement of social life. At least he aims to be open-mindedly cautious about any practical changes made in the name of his science.

Social science like natural science is aware of the fact that sooner or later it owes a debt to the society and its culture which makes the scientific examination of its data possible. Yet, due to this inveterate craze to alter matters overnight, some people are impatient with those who refuse to rush into the public forum with proposals to improve our social living.

To the writer, the very insistence on programs from anxious folks in our society is but a phenomenon to be examined and analyzed. It is frequently forgotten that this urge to improve the world is a part of our culture and that it is only to be understood and handled as such. There are two aspects of this which should be discussed briefly. One is the doctrine of progress and the other is the doctrine of good and evil.

Formerly many men thought that society was going down hill. Others imagined it was advancing. The doctrine of progress itself has a cultural history. The notion of evolutionary stages in history was current among certain early Greek thinkers. There is something of the idea of progress in St. Augustine's philosophy of history. Yet, it was in modern times, following upon the heels of commercial expansion and material invention, that the doctrine of progress got its firmest footing. In the eighteenth and early nineteenth centuries the theory of progressive social evolution became deeply rooted in Western culture. Even under the shadow of the guillotine Condorcet expressed an all-absorbing belief in progress:

> The result of my work will be to show by reasoning and by facts that there is no limit set to the perfecting of the powers of man; that human perfectibility is in reality indefinite; that the progress of this perfectibility, henceforth independent of any power that might wish to stop it, has no other limit than the duration of the globe upon which nature has placed us. . . . What a picture of the human race, freed from its chains, removed from the empire of chance as from that of the enemies of its progress, and advancing with a firm and sure step on the pathway of truth, of virtue, and of happiness![3]

Similar notions persist down to the present. Any one who is critical of such ideas is dubbed a pessimist. Witness our calling W. R. Inge the "gloomy dean."

For the social psychologist it is interesting to discover whether the idea of progress may actually come to influence the investigations and reforms made by men in contemporary society. Optimism for the future is quite as dependent on economic and political forces as on any ideology, so that whether this idea can overcome possible inevitable limitations to social change is open to doubt. The principal difficulty with the whole notion of progress is to find any objective criterion of progress. In terms of increasing complexity of material culture it is easy to measure change. Whether this shall be called "progress" is another matter. Does progress refer to moral improvements, to such vague and uncertain criteria as "human happiness"? Or does it concern only material change? And does our material culture mean "progress" when we witness contemporary economic maladjustments between production and the distribution of wealth? To just what items in our lives does it apply? Is progress to be measured in terms of collective organization as Professor Ellwood imagines and as the Russian communists attempt to put into effect, or in terms of increased individual liberty as Bertrand Russell proposes? Is a kind of hedonistic selection to be the basis of our progress, or a severe moral organization of society welded together for some collective aim? All such questioning throws us at once into the second aspect of this matter of reform, namely, the problem of good and evil.

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[3] Quoted in K. Young's "Social Psychology," 1930, p. 448.

Born of ancient Persian or possibly older origin, the doctrine of two rival forces in the world, light and darkness, good and evil, has come down to us, largely through Christian ideology. Man is seen as ever struggling with the evil forces about him. His salvation lies in reducing the evil in the world to a minimum or, better still, completely annihilating it by the domination of good. Anciently, and even to-day in many quarters, the whole struggle of good and evil is personified in terms of a personal god and a personal devil, each aided by a host of angelic hosts, some good, the others bad. This demonology was rampant down to the age of science. It even now persists in the masses to an amazing degree. To-day, however, the followers of science conceive the problem of good and evil, not in terms of personal devils or angels, but in terms of material, biological and social forces. The handicaps due to climatic change, the disasters of bacterial infection in man and domesticated animals, the effects of poverty, prostitution and war, —these are illustrations of the contemporary evils. Over against them we put such good services as meteorological prediction, medical research eliminating malaria, typhoid, tuberculosis and other diseases, and legislative reforms concerning minimum wages, hours of work, punishment for white slavery and the fixing of international agreements to prevent war. But the problem is still phrased in a contrast to dual forces at work, one against the other.

To secure the good and to put down evil is considered progress. To lengthen the span of life, to eliminate disease, to abolish war—all these are evidences of this advancement. It follows from this that there is an anxious looking to science, as formerly there was to religion and magic, for some solution to the remaining social problems. Thus, the social psychologist is asked for his contribution to the question of how to improve the intelligence of the voter, how to allay prejudice, how to prevent mob action, how to offset the bad effects of propaganda, and how to improve the quality of social leadership. Often there is a pressing demand for such panaceas before we have the slightest objective knowledge of the matter in hand.

Because of the recency with which social psychology has come into the field, it is imperative for its ultimate service to humanity, not to demand of it pat formulae for making the world better. Only when it has accumulated a sufficient body of facts may we begin to make generalizations and lay out hypotheses or attempt to frame tentative laws. The writer sees nothing immediately ahead which encourages him to believe that this stage of the science will be reached for a long time. In the meantime, the description, observation and tentative analysis of conditions is about the best we can offer. Let him who wishes make what he will of the situation. This raises the legitimate query as to the relation of science to the technique of improvement or control. Some attention to this problem may make it clearer why the scientist is not necessarily himself concerned with offering measures of reform.

Science is concerned with objective, impersonal description, observation and experimentation. It is essentially analytical. It is interested in cutting out certain facts, in terms of its premises, from the total reality. Science is necessarily a closed system within the confines of its own premises and conclusions. Given certain fundamental standpoints and methods, science can never rise higher than these sources. Eddington puts it thus in the closing lines of his book, *Space, Time and Gravitation:*

> We have found that where science has progressed the farthest, the mind has but regained from nature that which the mind has put into nature. We have found a strange footprint on the shores of the unknown. We have devised profound theories, one after another, to account for its origin. At last, we have succeeded in reconstructing the creature that made the footprint. And lo! it is our own.[4]

Science is always to be considered from its own particular frame of reference. There are many people who fail to recognize this. They expect science to answer questions it never intended to answer. Science is not concerned with WHY but only with HOW and WHAT. The WHY may be left to another branch of knowledge, religious philosophy. Although the premises of science may relate themselves to a particular metaphysics, the essential matter of science is to discover how and what the universe is and does.

When it comes to the matter of putting science to work, we enter the dimension of techniques. In a way, we go over to art, for technology and art are closely related. Art, properly speaking, is frequently a form of fantasy engineering or an extension of our world into the realms of imagination. Technology and art both use the principles and materials of science. The bridge builder draws from physics, chemistry and mathematics. He also may have occasion to employ the principles of psychology in handling his men and the matter of economics in estimating costs of production. Thus, the engineer derives his principles and materials from various fields and weaves them together into formulae for practical use. It is not different with the social engineer, to use a somewhat outworn term. He may draw his principles and materials from biochemistry, from political science, economics, sociology and psychology in developing a health program, a new housing project, or a scheme for the care of neurotic children. All of these special fields contribute something from their sciences, which were developed without specific reference to this or that particular social invention or device. Out of this matrix, the social engineer or artist creates his new plan or project.

Art, then, in the sense of social technology, is not altogether unlike art in the narrow sense of the "fine arts"—literature, sculpture, painting and music. Art is fundamentally synthetic and creative. In this it is unlike science, which is analytical and objective. Art is, in a way, more akin to certain aspects of philosophy than it is to science.[5]

The significant thing to recall is that social engineering or applied social science is a creation from elements of science and common sense, in reference to particular situations. In contrast, science proper must rest upon analysis. It has in its method no reference to the practical application. The following quotation from W. I. Thomas is in point:

> The examples of physical science and material technique should have shown long ago

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[4] A. S. Eddington, "Space, Time and Gravitation," 1920, p. 218. *Cf.* F. Znaniecki, "Cultural Reality," 1919, for a profound analysis of the whole problem of science, especially social science, in relation to the culture out of which it springs.

[5] Unless, of course, we consider science in the sense of the philosophical integration of its principles, when even science stretches beyond the laboratory and arises out of man's reformulation of his facts into theories.

> that only a scientific investigation, which is quite free from any dependence on practice, can become practically useful in its applications. Of course, this does not mean that the scientists should not select for investigation problems whose solution has actual practical importance; the sociologist may study crime or war as a chemist studies dye-stuffs. But from the method of the study itself all practical considerations must be excluded if we want the results to be valid.[6]

One factor remains to be considered in discussing the relation of social science to social reform. In the field of social change, social ethics always intrudes itself. In fact, social values, with which ethics is concerned, are a part of the data of social science. Certainly the value factor in behavior must be considered in social psychology. It is one thing to consider social value as the object of study in analyzing a behavior situation and quite another matter to consider social values themselves, in relation to consciously planned social reforms. In dealing with those phases of conduct of the person which touch the mores especially, it is necessary to consider value meanings. Yet we must not confuse the efforts made by willing social scientists to offer their own interpretations and values as to what to do, with the more objective treatment of values as merely a part of social data. A good deal of earlier social science and social psychology often confused ethics and science. By this we have merely delayed the more necessary fundamental description and observation of our data and the gradual formulation of hypotheses or tentative laws, without reference to this or that particular social program.

When the matter of social ethics is introduced, one is confronted at once with the ancient query: What is the Good? What values are Right? Whatever is good or right is to be considered relative to the whole culture at the time. Too frequently social scientists have discussed institutions and social practices from the angle of their own moral code, with the result that they have made most fallacious judgments and conclusions about these matters in regard to their own and other cultures. So far as our own good and right are concerned, especially in the matter of future change, it is the business of the social engineer and the community to bear in mind this relativity of values. It is doubtful if a new *good* or *right* can cut across historical values. Thus, change, however we may conceive it, relates to historical antecedents. Even the changes in revolution and in rapidly moving times like the present, when industrial and commercial inventions have so wrought upon the face of social reality, can not escape the influences of the past. The social psychologist, then, utters at least a caution to the social engineer. The latter must not forget in formulating his projects and his values that these, to be effective, must have some vital and fundamental connection with the social-cultural past out of which they arise. Many a good reform has blossomed but to die in the withering sun of social realism. It was knowledge of this fact that led State Senator Plunkett, of New York, to utter his famous remark: "Reformers are Morning Glories." Unless reforms have within them the germs of growth in relation to what is already around them, they will never succeed. Social engineering, like all good art, is only possible in reference to the personal-social and cultural matrix out of which it arises.

SOCIAL PSYCHOLOGY AND SOCIAL BEHAVIOR

Social psychology, as a scientific discipline, is in its earliest stages of development. It deals fundamentally with the personality in its social-cultural setting, that is, with the personality as it is affected by other persons and as it, in turn, affects them. Moreover, these inter-effects must take into account two aspects: environment and organism. It is clear that it is through other personalities and their works that the person is developed.[7] These influences, at least for descriptive and observational purposes, may be divided into two major categories. One of these, for want of a better term, we call personal-social influence, defining this to mean the person-to-person relationship which was not standardized or conventionalized into cultural patterns. These are the influences that develop around physical differences in size of persons, strong and weak, old and young, adult and infant. They develop out of dispositional differences, dependent upon divergences in intelligence and emotions. The second set of influences are those which grow out of cultural norms: the folkways and mores, the customs, traditions, conventions of the social groups to which we belong. Some of these relate to narrow groups, like family standards of wealth, others to the community, as in dress, manners, or morals; and still others to secondary or special interest groups, such as trade unions, employers' associations, religious sects, political parties, criminalistic gangs, and so on.[8]

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[6] W. I. Thomas and F. Znaniecki, "The Polish Peasant in Europe and America" (2nd edition), 1927, Vol, i, p. 7.

In actual living, these two influences are constantly intermixing with each other, but for purposes of study it seems well to distinguish between them. Out of personal-social influences of person on persons, cultural norms are constantly being fashioned. The matter is nicely illustrated in fashion and in public opinion, especially in this day of propaganda. It is also true in the development of the moral codes. Some person or small group of persons may experience a crisis. When they solve it in some particular way they may set out consciously or unconsciously to project their solution, that is, their definition of the crisis or situation, upon the larger group or groups to which they belong, be it neighborhood, community, trade union, church organization or nation. In this matter, again, the power of the older mores and folkways may modify and divert the direction of the new solution. Because of the dominance of these cultural habits, the modern social reformer may encounter difficulties in attempting to project, successfully, his pet theories and programs upon his group. Accretions to the mores are gradual. Nevertheless they do arise out of personal-social experience in the first case, modified always by past cultural norms.

The third factor to be taken into account in social psychology is the organism itself. First, we must consider it in its individual or psycho-biological dimensions, and then in the sense of a developing, changing person. On the side of the psycho-biological individual, we must examine his physical, intellectual and emotional make-up in terms of behavior mechanism and variability in structure. As the organism is thrown into the social milieu at birth, the psycho-biological mechanisms are directed toward this environment from the beginning of life. The earliest environment of the child is colored by social influences. It is out of the interplay of organism and environment, personal-social and cultural largely, that the personality is developed. What the person becomes depends largely upon the group contacts and their effects upon his organic nature.

The organic nature of man determines, in part at least, the whole personal-social and cultural environment itself. When we observe the person in operation in relation to other personalities, we see that emotions and feelings as well as intellect must be taken into account. The former furnish the basic drives or motives to conduct. The latter is largely given over, apparently, to rationalizations and conscious adjustments on the one hand, and to furnishing the internal or subjective counterpart to our personal-social and cultural environment on the other. That is, the imagery, the ideas and attitudes within the organism reflect very largely one's conditioning to personal-social and cultural factors in one's experience. In this manner they pre-determine to a large degree how one will respond to future personal-social and cultural stimuli. In other words, the social psychologist examines not only the mechanisms of conditioning and integration of responses, but that content of ideas and attitudes which have been accumulated from experience. This content is what Thomas refers to as values and what Znaniecki and Faris term social objects. Biologically, the seat of this content seems to be largely the cerebral cortex, for it is through this section of the central nervous system that learning takes place. With all these effects, left over from conditioning, go profound emotional and feeling accompaniments. And the biological roots of the emotions and feelings lie in the autonomic-glandular system which is the result of inheritance and maturation.

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[7] This is not to gainsay that consideration of other aspects of environment, physical and biological, is necessary to a full treatment of the social-cultural process.

[8] See my "Social Psychology: An Analysis of Social Behavior," 1930, for a treatment of the difference between personal-social and cultural conditioning.

If present-day social psychology exposes man as largely irrational and emotional, rather than as coolly rational and intellectual, it is because the evidence seems overwhelmingly to show that behavior is motivated by deep prepotent emotional-feeling trends. Upon them the personal-social and cultural influences work their way. The amazing thing is not that man is not the rational, calmly intelligent person in his social contacts that he was once pictured, but that social and cultural conditioning, after all, can so profoundly alter the direction which the prepotent tendencies take.

The writer is of the opinion that the recognition of this fact will go far in giving a more satisfactory direction to any social reform or change which groups may wish to undertake in the interests of society and individuals. The writer does not believe that progress, whatever it be, lies in the direction of crushing out the emotions and feelings and substituting the reign of the intellect. It consists in directing, by the best knowledge we have, the emotions and the feelings into those channels which the social ethics of the time, themselves based on a recognition of the place of emotions and feelings, dictate. Science alone can not save us, unless we couple with it an art and philosophy which will recognize the power of emotions and feelings in the motivations of human conduct.

SCIENCE SERVICE RADIO TALKS

PRESENTED OVER THE COLUMBIA BROADCASTING SYSTEM

THE UNITY OF LIFE

By Dr. C. E. McCLUNG
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THE astronomer finds in the heavens a multitude of celestial bodies, which he classifies as stars, planets, satellites, nebulae, comets, meteors, asteroids, etc. He traces the birth, maturity and senescence of universes and, by spectroscopic analysis, discovers that all these varied heavenly bodies contain the same chemical elements. Our own earth, once thought to be the center of the Universe, takes its place as a minor unit of one galaxy. System, law and order prevail —an underlying unity pervades the apparent diversity.

Because of the ability of the physical scientist to predict the coming of future events, his opinions are accepted with little question, even when they come into conflict with our most cherished beliefs, but quite the opposite is the case when the biologist speaks upon the nature and relations of living things. Here we often hearken back to medieval times. State laws are enacted practically forbidding people even to think upon biological matters under penalty of imprisonment. People who admit their incompetence to pass upon astronomical questions will categorically deny the validity of biological theories which have the support of all scientists. The reason for this, of course, lies near at hand—every person is in himself a living being and, therefore, considers himself prepared to pass judgment upon matters relating to his class. Unfortunately, he overlooks the fact that in addition to this general qualification, the biologist has given years of special study to the problem and therefore, if there is any virtue in mental application, should be much better qualified to think and judge in such a difficult matter.

The problem of how living things are related may be stated in its general terms very simply. There are now dwelling upon the earth some millions of different kinds or species of animals. A study of geological history shows us that in past ages many more millions of kinds existed and died off. The main question at issue is: are these manifold forms related to each other, or did each originate independently—these are the only alternatives. I do not wish to argue the question on this occasion, but merely to present some of the evidence upon which a reasonable decision must be based.

The facts usually taken into consideration are those relating to structure, because they are the ones which most clearly and easily distinguish one kind of animal from another. Amid these admitted diversities, degrees of resemblance are sought and used as measures of relationship. Logically this seems to be little justified as a primary approach to the problem. If it is believed that all animals are related to each other, then search should be made for qualities common to the entire group. If many millions of kinds of animals are alike in a series of essential characters, then the assumption that they arose independently becomes mathematically improbable.

What are the admitted resemblances between animals? First, there is the limited range of physical conditions which they require for existence. So far as the astronomer can discover, our earth is the only celestial body which presents these conditions fully. Sunlight, water, oxygen, a limited amount of carbon dioxide, a narrow range of temperature variation, and many other circumstances must be present in their entirety for life of any kind to exist. Since it is obvious that an animal is essentially a reaction mechanism, the circumstance that all animals react to a common and unique set of physical conditions argues strongly for their common origin.

The second point of resemblance is that they are composed of the same kind of substance. This common building material is called protoplasm, or primitive substance. It is of a watery, glue-like nature, and has many of the properties characteristic of the class of compounds called by chemists "colloids." Whatever activities animals manifest they are the ones inherent in the basic substances of which they are composed. In some peculiar way this has become, as it were, a time reservoir. Only after repeated and accumulated experiences do modifications become impressed upon protoplasm. There are, therefore, as many kinds of protoplasm as there are of animals, each of which has incorporated into itself the results of its past experiences. In some way this process accelerates with time, so that development and change are cumulative.

In the third place, we note that not only are all animals composed of the same kind of substance, but they have it organized into the same sort of structural units. It is just as if all houses should be constructed of baked clay which had been formed into units, or bricks, of different sizes and shapes. Only in very recent times have we known these living building blocks, because they are very minute and require the highest magnification of the microscope for their study. The discovery that the unit of structure and function in both plants and animals is this so-called cell is perhaps the most important in all biology. Our understanding of how living things are formed and how they act depends upon our knowledge of the nature and behavior of these organic units. It has been well said that all problems of modern biology are cellular problems. Practically this means that whatever we discover about any one cell has meaning for all cells. Some of the most fundamental facts relating to the nature of vital processes in man have come, for instance, from the study of cells in insects and even in plants.

Finally, we observe that no matter how varied in size and form animals are, they perform just a few striking and unusual acts necessary for their existence —in other words, they relate themselves in limited and specific ways to their common environment. There are manifold degrees of speed and perfection with which these acts are performed, dependent upon the structural mechanism employed in each case, but, whether high or low, all animals are alike in the things they do. What are these unique vital functions?

First, since animals are absolutely dependent upon their environment, they must be able to sense this so that they may adjust themselves to favorable and to unfavorable conditions, *i.e.*, they must have the power of perception. They must be able to distinguish between light and darkness, heat and cold, food and poison, friend and foe, and so on. This is due to a property of protoplasm known as irritability.

To take advantage of perceptual reactions, animals must be able to move. This faculty is highly developed in animals and depends upon a quality of protoplasm called contractility. Certain cells are modified in a characteristic manner so as to make possible a large degree of contractility. In higher animals these are called muscle cells, and they are much the same whether found in insects or in man.

To produce movement or any change, energy is required. In animals this is secured by burning up their substance. Such losses are made up by taking foreign materials and transforming them over into the nature of those destroyed. The body of an animal is like a chemical laboratory where there goes on a constant series of destructive and constructive processes. These chemical changes come under the designation of metabolism and, again, are common cellular processes in all animals.

But the most striking and entirely unique characteristic of living things is their ability to reproduce themselves. Given the necessary physical conditions and protoplasm, as such, is immortal, but its various embodiments are constantly wearing out and dying off. To secure the perpetuity of their kind, animals accordingly reproduce themselves, and so there is a constant succession of individuals of any given variety, some of which forms go back for millions of years. Here again, we deal with a cellular process, for each animal at one time in its existence is a single cell and becomes a body of billions or trillions of cells through the reproduction of the original one. It is probably true that, in turn, all the parts of the cell reproduce themselves down to the chemical units which compose them.

What has been asserted of animals is essentially true of plants also. Our knowledge of living things, including man, enables us, therefore, to state the following facts: (1) they are made up of one kind of substance, protoplasm; (2) this common material is organized into a single type of unit structure, the cell; (3) these cells are differentiated for the performance of a common series of functions and (4), for the performance of these acts, a very limited series of physical conditions, unique in their combination, is required. When viewed from the functional standpoint, the manifold diversities of form in animals are, therefore, only adaptations to secure various degrees in expression of a common and essential series of vital processes.

ANIMAL GRAFTING

By Professor H. H. COLLINS
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We are inclined to think of that rarely gifted and many-sided American, Benjamin Franklin, as a man of a very practical turn of mind. We remember him not only for his achievements as a statesman, but also as the author of "Poor Richard's Almanac." Less well known is the fact that he was one of our pioneers in the field of science, and that, in the course of his investigations, he sometimes performed experiments such as his flying a kite in a thunderstorm, in which the Poor Richard type of mind might well fail to see any rhyme or reason. Electricity, in which Franklin was greatly interested, after being, as skeptically minded persons were wont to say, nothing but a college professor's toy for a century and more, finally came to revolutionize human daily life,—and the end is not yet.

Many of the experiments of modern biologists might well be compared to Franklin's kite-flying venture. Just as in the realm of electricity a study of the behavior of this mysterious force under every conceivable set of conditions ultimately led to the discovery of means of harnessing it for the service of mankind, so the study of living matter under all conceivable experimental conditions may be expected to lead to a knowledge of life with possibilities of its control in ways undreamed of today.

The very important place which plant grafting holds in agriculture is a matter of common knowledge. Less well known, however, are the results obtained in the grafting of animal tissues. As in plants, pieces of two different individuals may be joined in permanent union.

In animal grafting the individual receiving the graft is known as the host; the one from which the graft is taken is the donor. Grafts take most readily when the host and donor are one and the same animal. Grafts between different species or still more distantly related animals are difficult, if not impossible, to make, due to blood incompatibility.

Transplantations are easier on embryos than on adults. Before the brain and blood circulatory system are developed the head regions of two frog embryos may be successfully interchanged, but this would be impossible in adults. Heads may be interchanged in adult insects. This is possible because in insects, the body structure is such that removal of the head does not seriously interfere with breathing and circulation. Certain worms may be cut in two and the body of a second worm of the same kind inserted thus making an abnormally long worm. In certain instances, two animals may be joined together side by side, Siamese twin fashion. This has been done with rats, birds, frogs, and newts. This type of operation is actually a blood transfusion experiment on a large scale. Animals of opposite sexes have been united in this manner in order to study the effect of the secretions of the ovary and testis upon the development of the so-called secondary sexual characters.

Among various scientific problems attacked by the method of tissue transplantation, one of the most important is that of the influence of the host on the graft. One of the classic experiments in this field performed some years ago was the transplantation of the ovary of a black guinea-pig into a white guinea-pig whose ovaries had been removed. The offspring of this white female mated with a white male were *black*. Normally the offspring are white when both parents are white. In this case the graft was uninfluenced by the host. Experiments of this sort should however be continued through a longer period of time in order to determine whether or not some change might eventually become evident.

Parts of the body of an animal of one species have been grafted on an individual of another race or species to determine whether the specific characters of the graft can be changed by the influence of the host. It has been found that the rate of heart-beat differs in embryos of certain species of amphibians. When the heart is transplanted from one species to another, it maintains its own characteristic heart-beat. Specific differences in rate of growth and in size of body parts have also been observed. These differences may persist for a time following transplantation, but, in general, are gradually brought under control of the host's growth regulatory mechanism.

Not only does the host, in varying degree, exert an influence upon the graft, but the graft may affect the host. The most striking effects of this sort are produced by the secretions or hormones thrown off by certain types of grafts into the blood stream of the host. A graft taken from a hormone secreting organ may produce profound changes in the host. Animals engrafted with ovaries or testes, for example, assume more or less distinctly the characters of the sex of the animal from which they received the graft.

One of the profoundest problems which confront students of life in its various manifestations is that of the gradual development of a highly complex adult body with its many kinds of very dissimilar and highly specialized types of cells, tissues, and organs from the relatively simple fertilized egg cell. Soon after fertilization, the egg cell divides into two cells, identical in appearance. These divide and the process continues, but the daughter cells gradually become more and more unlike until finally the muscle, bone, nerve, gland, and cells of many other types appear. Some interesting discoveries have been made in studying this problem of the development of embryos by the transplantation of tissues from one embryo to another, or from one part to another of the same embryo. It has been found that certain groups of cells may for a time control the development of other groups of cells. The lens of the eye develops in the embryo from the small area of skin beneath which the rest of the eye comes to lie after growing out as a stalked structure from the brain. In certain amphibians, the cells in this so-called optic cup force the overlying skin cells to form the lens. If this patch of embryonic skin cells is excised and transplanted to any part of the body it becomes a part of the normal skin of the adult animal. If skin from any other part of the body of the embryo is placed as a graft on the side of the head above the optic cup, it will differentiate to form the eye lens. However, if the lens area has started to develop as lens, it will grow into lens although transplanted to some other region of the body.

At a certain stage in the development of the amphibian embryo a mass of cells lying just underneath the developing brain acts as a controlling organization center for surrounding tissues, determining their fate. When this mass of cells is grafted into the undifferentiated abdominal region of another embryo, it induces there the development of a second brain and spinal cord from cells which would normally have formed stomach, kidney and other abdominal organs. This particular organization center soon loses its controlling power, later development apparently being controlled by a succession of organization centers which arise in various parts of the body.

In the work in the field of animal grafting being conducted in the laboratories of the Department of Zoology of the University of Pittsburgh, a small am-amphibian relative of the common frog is being used as experimental material. This form is commonly known as the red-spotted newt, in some localities erroneously called the "water lizard." This small animal which has somewhat the appearance of a miniature alligator has a very striking color pattern over the general body surface.

The under surface of the body is a bright lemon yellow, with numerous rather large black spots, fairly uniformly distributed. In sharp contrast to this, the animal's back is a dark greenish brown, mottled with black splotches and further marked by two rows of brilliant red spots, one on either side of the mid line of the back. The two types of skin do not shade gradually into each other along the sides of the body but are separated in very clear-cut fashion along what we have called the lateral border. How such a color pattern could have arisen in the evolutionary process, we are at a loss to determine. Equally mysterious is the development of this pattern in the embryo. In the growth of an individual from the egg to the adult, cells as unlike as those of the brain and liver develop from common ancestral cells. The differences in coloration of the skin on upper and lower surfaces of the body may be due to differences between the skin cells of the two body surfaces, slighter in degree than those between brain cells and liver cells. Another possibility is that the difference in coloration may be due to difference in location. It is known that in early stages of the development of an embryo the ultimate fate of cells is determined by the position they happen to occupy. If we could interchange the two cells, one of which would normally ultimately give rise to brain, the other to muscles, the ancestral brain cell would produce muscle cells, the ancestral muscle cell, the brain.

To determine whether the marked differences in dorsal and ventral skin of these two types were fixed and unalterable or due merely to difference in location, skin transplantation experiments were carried out. The animals were anaesthetized and small patches of skin were removed. These grafts were rotated through 90 and 180 degrees and replaced in the original location. The animals were kept for 24 to 48 hours under an anaesthetic. When they recovered none the worse for the experience, and resumed their normal movements, the grafts remained in place, the cut edges of the skin having united during the inactive period. Lemon yellow ventral skin of the graft was now surrounded by dark dorsal skin, and *vice versa.* During a period of several months after operation, the grafted skin slowly became reorganized and assumed the appearance of the surrounding skin. In some animals, the reorganization is exceedingly slow and is incomplete more than a year after operation.

In the process of reorganization, the little black color or pigment cells appearing under the microscope like miniature tree stumps with many roots, behave in a very characteristic fashion. Yellow skin grafted upon the back is slowly invaded by hosts of black pigment cells from the surrounding dark skin. Some of these invaders become clumped together to form large dark spots, while most of them remain scattered to form the dark background characteristic of the normal dorsal skin. The red pigment in the brilliant spots appears to exert a strong attraction on the black cells. The black cells crowd about the red pigment spots, forming a dense black border. We do not have as yet any explanation of the behavior of these pigment cells. The slow reorganization of the color pattern indicates some differentation, but the two types of skin do not have their characteristics fixed and unalterable. Placed in a foreign environment they gradually conform to that environment. While it may be true that a leopard cannot change its spots, a salamander can.

Among the relatives of the red-spotted newt of the eastern United States is the brown newt of the Pacific slope and a newt of similar appearance found in Japan. Skin grafts have been interchanged between these species with interesting results. The more distant the relationship between the animals the greater the violence of the reaction, the foreign tissue being resorbed and replaced by host tissue. In this group of animals skin grafts seem to afford a very delicate test of relationship through the differential rate of resorption of the grafts. According to the evolutionary theory of the origin of the many kinds of animals in the world today, all living beings are blood relatives of each other. In the working out of family trees nearness of relationship has in the past been based mainly upon the degree of resemblance in anatomical structure. To some extent these relations, inferred on the basis of structure have been verified by blood tests. The method of skin grafting appears to offer an additional and exceedingly sensitive means of determining evolutionary relationships.

HOW SCIENCE STUDIES THE CHILD

By Dr. ARNOLD GESELL

DIRECTOR OF THE YALE CLINIC OF CHILD DEVELOPMENT

SCIENCE is a mixture of curiosity and reasoning. It represents the determined, systematic effort of man to understand the world in which he lives. The child is part of that world—a very important part. The child is a portion of the scientifically explorable universe, quite as much as the sun, the stars and the ether. Prompted by curiosity and by the needs of civilization, the physical sciences are penetrating the mysteries of heaven and of earth. There is now a huge fund of knowledge which gives increasing control over the natural forces of the physical world.

In comparison, our knowledge of the child is meager. But the child is part of one vast order of nature, within the scope of science. The laws which govern his behavior and his development are discoverable. He challenges the same scientific inquisitiveness which impels chemist and physicist to investigate the constitution of the atom. The child is more complicated than the atom, but not less lawful. The very conquests of physics, chemistry and engineering have created new problems for society. Our mechanical civilization has grown so complex that we can not perpetuate it without a deeper comprehension of human nature. Each generation must rear a stronger army of children, mentally fit to carry forward an increasingly complex culture. As a measure of self-protection and of survival, the race must learn new methods for improving mental stamina and psychological adaptability in the young.

Consequently, the scientific study of child development has expanded at a very rapid rate in recent years. Centers of child research have sprung up at points as far flung as Moscow, Geneva, Vienna, Berlin, California, Iowa, Minnesota, Washington, New York. America has become a leading country in this scientific movement. Everywhere our universities are establishing laboratories, nursery schools, guidance clinics and institutes for the investigation of child development. Infants and young children are no longer strange sights on a college campus. They have become part of the scheme of science and of education. And this has had a humanizing effect on all concerned. Adults have benefited along with the children.

At present we know as little about the psychology of the child, about the nature and the needs of his mental life, as was known about the geography of the world at the time of Columbus. There are large, almost unknown continents of truth into which hundreds of investigators have entered. An important field of exploration has to do with the significant problem of individual differences of perception, of memory, of speed and accuracy, of movement, differences in posture, in imagination, intelligence, endurance, talents, interests, skills and aptitudes. Even in such a simple trait as right-handedness or left-handedness there are individual variations. These variations are being investigated by methods of careful measurement, by comparative observations, and by intensive individual studies. Sometimes children are observed continuously night and day, or at brief intervals, or over a period of years.

Instruments of great precision are frequently used. Reactions are recorded on strips of waxed or smoked paper; movements are photographed; stenographers register full details; even sensitive electrical apparatus, like the galvanometer, may be brought into use. Literally hundreds of mental tests and scales have been devised to measure human differences. When an amateur without scientific training or scientific standards attempts to apply these tests they become useless and misleading; but when applied with critical caution they are valuable. We must remember that mental measurement is only in its beginnings. The time will come when the sciences of human behavior will have techniques which will not only measure the capacities of the child but will predict and guide the development of his characteristics.

To study the genesis of individual differences it is necessary to study the processes of mental growth. The mind grows. Behavior grows. This growth begins even before birth. It expresses itself in changing patterns of behavior. So swift and continuous are the changes that it is difficult to keep up with the pace that the infant sets. In the Yale Clinic of Child Development we have had to call to our aid the motion picture camera. The cinema sees with an all-seeing, impartial eye and it records with an infallible memory. We need such a powerful recording instrument for the exploration of the bewildering and almost kaleidoscopic eventfulness of human infancy.

Normal infants are periodically studied at four-week intervals throughout the first year of life with the aid of a specially designed clinical crib which permits the application of psychological test situations under controlled conditions. The crib is housed in a hemispherical photographic dome equipped with a one-way vision screen which permits free observation by effectively concealing the observers stationed outside. The dome is equipped with cinema cameras which make permanent systematic records of the behavior characteristics of the infant—his posture, locomotion, perception, prehension, manipulation, social reactions and spontaneous and problem-solving activities. Simple test materials like small red cubes, pellet, string, bell and formboard are used to call out characteristic patterns of behavior.

The cinema captures this visible behavior. The records are then subjected to detailed analytic study by means of a specially designed projector which throws the image of the behavior on a viewing glass. The infant relives on the cinema screen. We can see him as he was at four weeks, eight weeks, twelve weeks, sixteen weeks, and so on. By simultaneous projection we can make an immediate comparison of any two age levels of maturity. By such methods it is possible to measure and to chart the patterns of behavior which express the laws and norms of early mental growth.

Many studies both in this country and abroad show that important individual differences declare themselves early. Take, for example, such important traits as artistic and musical ability, drawing, dramatic and mechanical abilities. They have been studied at many age levels. Recent research has pushed the quest for early indicators down to infancy and the preschool years. If scientific progress continues at the present rate, it will be possible for later generations to detect individual variations from the normal at very early ages. That will lead to prevention and cure of many behavior disorders. It may some time also be possible to discover gifted individuals of the community in the cradle and the nursery. Indeed, it will become necessary for future society to greatly perfect the education of all children in the first five fundamental years of life. Science alone can determine the scope and the hygiene of that fundamental education.

What are the limitations of education? What are the relationships between heredity, environment and development? This is an important field of inquiry, approached from many angles. Numerous comparative studies are under way, dealing with children from different stocks and races; from different social levels; from different family origins and contrasting educational opportunities. There is a large and growing literature on twins. The study of twins has almost become a science in itself. Identical twins and dissimilar twins, twins reared apart, twins reared together, have been compared and intercompared; their psychological traits, their diseases, their crimes, their achievements, their relative responses to different methods of training have been investigated. Identical twins are an experimental touchstone to the old and fundamental problem of nature *versus* nurture.

The great problems of inheritance, however, are being solved through study of plants and animals as well as of children. The biological sciences are all closely related and they draw upon each other. The more fundamental laws of growth and development are universal. Science seeks and finds truth everywhere. Many of the important facts that we know about the nutrition, the disease, the nervous system, and even the behavior of children have come in a roundabout way, through the study of plants and animals in the laboratory. We must be duly grateful for what the scientist has learned from the white rat, if not grateful to the white rat itself!

The child is part of the whole order of nature. To some degree his growth is governed by the same wonderful laws which control the growth of plant and animal organisms. But the child is also enmeshed in an invisible web of social relationships. His spiritual growth depends upon this web of human relationships. Science must study him as a social being in reaction to parents, to brothers and sisters and to companions. By investigating the growth of his social behavior from the moment of birth it becomes possible to define the laws and the processes of personality formation. Here lies the ultimate goal of child research.

Science may never solve the deeper mysteries of the soul, but it has already begun to cope successfully with the interpretation of human personality. Numberless studies emanating from laboratories, clinics, schools and hospitals have described varying patterns of personality in health and disease. These studies, too, are being pushed backward to the stages of infancy and early childhood. Human personality begins to loom up as something tangible, which in measure can be understood and controlled.

Our scientific knowledge of child personality is still meager and imperfect. But if this present meager knowledge could be put into application it would perceptibly improve the social and the family life of the nation. Even difficult human problems yield to the methods of science. And some of the most perplexing of these problems will be solved by delving deeper, through child research, into the processes of personality formation.

SCIENCE AND THE RADIO

By AUSTIN H. CLARK
U. S. NATIONAL MUSEUM

RADIO broadcasting in its relation to science is a rather complex subject which is divisible into three more or less distinct sections. The first of these sections concerns the audience, the second the radio stations and the third the scientific organizations.

At first sight it may appear that these divisions of the subject are given in quite the wrong order—that the scientific organizations should receive the first consideration. What is the reason for the reversal of this order?

The reason is that success in any undertaking is based upon a thorough appreciation of the grim realities inherent in that undertaking. We must understand the basic principles involved and be prepared to accept the situation as we find it.

The situation in regard to radio talks is very simple. The expenses connected with all radio talks are ultimately paid by the audience, and the success of any series of radio talks is dependent upon the willingness of the audience to continue to pay the bills.

The immediate expense of broadcasting is borne by the radio station. Nearly all radio stations are operated for the purpose of making money in one way or another, largely indirectly. Radio stations, therefore, can afford to add to their programs only such talks as will increase the number of their listeners, or at least will not cause it to decrease.

Through the radio stations scientific organizations are enabled to reach a large section of the public at practically no expense to themselves. They are the beneficiaries of a large amount of valuable advertising which, though received without cost to them, means a considerable expense to others, who are quite justified in anticipating that this expense shall in some way be counterbalanced.

So it is evident that in any discussion of the relation between scientific organizations and the radio the audience must be first considered, then the radio stations, and the staffs of these organizations must be prepared to pay due regard to the idiosyncrasies of the one and the necessities of the other.

Consideration of the audience and the radio stations demands as a prerequisite a severe deflation of the ego—especially on the part of the members of the staffs of scientific organizations. We must lay aside the idea that others wish to be like us, or wish to know as much as we do or are to any appreciable degree interested in what seems all-important to us. We must meet the public on the basis of the highest common divisor, intellectually speaking, always, of course, with the hope that this highest common divisor may be increased by our efforts.

The radio audience is composed of the general mass of the population—or rather of a cross section of the general mass of the population. Nearly all those who listen to the radio are more or less typical products of modern American education as it is administered in our public schools.

Education in this country formerly consisted chiefly of a close application to the works of Euclid, Vergil, Thucydides and others, stimulated and invigorated by a liberal use of the birch rod or its equivalent. In spite of its many faults, this system of education had many advantages. Among other things, it inculcated a great respect for knowledge and for individuals possessing an exceptional amount of knowledge. For in those days knowledge, as represented by the teachers, was combined with power—disciplinary power—symbolized by the birch rod.

In our modern public schools the birch rod, the emblem of the dignity, authority and power of knowledge, and hence of the learned, exists no longer. Vergil, Thucydides and the other Latin and Greek authors, symbols of a respect for the knowledge and culture of the past, have either completely disappeared or are in more or less total eclipse.

Education with us at the present day has become a matter of presenting information as nearly as possible in the form of a pleasant amusement, with an underlying idea of its potential economic value rather than of its cultural significance. Through their parents modern American children are induced to accept an education on the basis of a potential development of increased possibilities for accumulating dollars, whereas in the past children were forced to become educated in order that they might maintain the proper cultural level.

So the children in our public schools have little respect for their teachers, and consequently little respect for the learning that they represent. In our colleges the majority of the students listen respectfully to the professors because they or their parents have paid for that privilege, and expensive professors, like highly paid "movie" actors, are always more highly regarded than cheap professors.

This is not an indictment of our system of education. It is really an admirable system—the only system that is applicable to our entire population, and the only system which, in view of our traditions, would stand the slightest chance of success with our public as a whole. Vergil, Thucydides and the birch rod could never be imposed upon more than a very small percentage of any population, though they are exceedingly effective where they can be applied.

But this system of education leaves a very definite imprint upon the radio audience. Composed of individuals with active minds unfettered by any great respect for the traditions of the past, who have been subjected to a suggestive rather than an intensive education, the American public in its leisure moments naturally turns to the sensational and mysterious rather than to the cultural or informative aspects of affairs.

The public looks to the radio for amusement or diversion in some form or other. In the evening especially it craves the sensational and mysterious, the effect of a day's work on most people being to make them intolerant of any close contact with the realities of life—excepting murders, scandals and similar and comparable phenomena.

Most people are more or less optimistic up to lunch time, then apathetic, and after the close of the working day still more apathetic or even pessimistic. Sensationalism, therefore, is least appealing in the morning, and most appealing in the evening. This unconscious leaning toward sensationalism and distaste for any unnecessary contacts with the hard realities of life is accompanied by an unconfessed resentfulness toward education as that term is generally understood. The people have not the least desire to be educated after the fashion in which they were educated in school.

So radio talks given in a manner even remotely suggestive of a desire to instruct are bound to be pathetic failures. They must be wholly devoid of any suggestion that the speaker is better informed or more learned than the listeners. If after leaving school the public is to be induced to continue the acquisition of knowledge, the additional knowledge must be presented either in a form capable of potential interpretation in terms of dollars, or in the form of a more or less fascinating mystery.

We must constantly bear in mind that as a people we have no real respect for learning as such, and no respect for learned men unless they happen to be in positions of power of one sort or another.

At the present time the power of knowledge in our schools is symbolized by the text-books. Most pupils in the public schools have more respect for their books than they do for their teachers. A very important effect of the use of text-books in schools is to inculcate a feeling that printed information is reliable and authoritative wherever found. Most people in later life carry their respect for the printed page of the text-book over to the printed page of the newspaper, excepting only in regard to matters that concern them personally, or in regard to which they happen to possess special knowledge.

This makes of the daily press a very powerful factor in general education—indeed, the most powerful factor.

In the average mind information acquired from a book or from a newspaper bears about the same relation to information heard over the radio that established fact bears to gossip. Most people, before they are willing wholly to accept news of a startling or unexpected nature heard over the radio, wish to see it confirmed in print.

It must be constantly borne in mind that the radio is to a large extent a sort of family institution. There is nothing secret about it. Every one can hear what the loudspeaker is saying. From this obvious fact arise various complications and limitations which do not appear in connection with the printed page.

Theoretically, father is the head of the family. But not at all infrequently father's prestige is none too well established. Consequently, father is very sensitive. He does not care to hear the loudspeaker telling him in the presence of mother and the children—especially the children—facts of which he is ignorant. It is particularly obnoxious to him to hear the loudspeaker recite facts of which he is quite aware the family knows he is ignorant. Father is often equally sensitive about having the children hear facts from what he regards instinctively as a more or less irresponsible source, far more sensitive than he is about their learning the same facts—or even absorbing information characterized by a complete absence of facts—from a Sunday supplement.

Yet in spite of all that has been said, our American public is keenly and honestly desirous of learning new facts and new ideas, and surprisingly adept at understanding and appreciating them. In imparting new facts and new ideas the one condition to be met is that they shall be conveyed in such a way as not to put any one at a disadvantage through an implication of personal inferiority.

This is not a difficult condition to meet if it is thoroughly understood and appreciated in advance. The chief obstacle in the way of an adequate appreciation is that our educational system as a whole operates under two widely different sets of traditions, the purely native and thoroughly American traditions in the main underlying our public school system, and the imported and alien traditions out of which have grown most of our higher institutions of learning.

Why should the popular attitude toward science, and learning in general, be so very different in this country from what it is in England? The reason is very simple.

The one and only thing that commands general respect is power.

A hundred years ago in England power was to a very large extent hereditary. So far as possible, wealth and power were concentrated in certain families in which they were handed down from generation to generation. Those who inherited wealth and power were relieved of the necessity for striving to create power and wealth on their own account. They could, if they so wished, occupy themselves entirely with unpractical affairs. This many of them naturally did.

Almost anything a man of great wealth and power may do will be considered praiseworthy, no matter how ridiculous the same line of activity might seem if undertaken by a person of no influence. The hobby of a man of great power is always respected in proportion to the power he possesses, never through any real appreciation of the cultural or other possible values of the hobby itself. These values are later discovered (or invented) and brought forward primarily as an explanation of the superior mental equipment of the man of power—or in other words as a sort of excuse for actions that otherwise might seem peculiar.

Because of the great power which they possessed, no one thought of smiling at the Earl of Seaforth because he collected butterflies, or at Lord Valencia because he collected various animals on his travels, or at Sir Hans Sloane because he spent most of his time in Jamaica, whither he went as physician to the Duke of Albemarle, collecting plants and animals. Indeed, on Sir Hans' death Parliament, representing the British public, accepted his library and collections of all sorts on behalf of the nation, paying his executors twenty thousand pounds for them.

So in England it naturally came about that science and learning early became invested with an enormous prestige that had its origin not in any real appreciation of their intrinsic or cultural value, but arose from the deep appreciation of and wholesome respect for the immense power wielded by the classes to which they were largely confined.

Hand in hand with this went the idea that science, in order to be really respectable and worthy of emulation, must be pure science, as far removed from any possible economic application as its patrons were from the necessity for daily toil.

The English attitude toward science prevailing a hundred years ago was of course imported into this country. But here it failed to make any general impression. It took root in a few places, where it was confined to—perhaps more correctly besieged within—a few institutions of learning and learned societies, almost exclusively in Philadelphia and Boston.

Why this was so is not at all difficult to understand. Our social system was very different from that of England. Our inheritance laws were such that it was impossible to perpetuate power in successive generations indefinitely, and public sentiment was strongly opposed to all efforts toward that end.

The natural result of this was to exaggerate the importance of the personal accumulation of wealth, and hence to regard all forms of human activity in the light of their bearing on the accumulation of wealth.

In a new country with abundant unexploited resources the accumulation of wealth requires abundant energy and resourcefulness. Only a very limited amount of special knowledge, chiefly of the labor foreman type, is necessary. To those whose one aim in life is the accumulation of wealth, hobbies seem ridiculous and a waste of time.

So any appreciation of science, culture or learning was conspicuously absent from the American social ideals of one hundred years ago, excepting only in a few very limited groups which clung to the English traditions.

During the past century, and especially within the past twenty-five years, appreciation of science has vastly increased in this country. This increase in the popular appreciation of science has been based not upon its cultural aspects but instead has kept pace with its ever-broadening economic application—in other words, with its increasing value in terms of dollars.

At the present time science is more generally and more highly appreciated in this country than in any other, and more money is annually spent for research here than anywhere else. But in the minds of the great majority of our people science never has attained, and never will attain, the high plane of social respectability that it occupies abroad. It is useful and often mysterious, and therefore interesting and worth knowing something about. That is our typical American attitude toward science.

We who do our work in scientific institutions or in institutions of learning naturally see science from the English view-point. We like to flatter ourselves that we are engaged in a thoroughly respectable and even aristocratic occupation. It is a very satisfying and comforting belief, helping to smooth our path through life and doing no harm to any one.

But when we attempt to explain our work to others through a medium which, like the radio, reaches all classes, and chiefly those classes of the population that are most widely different from the academic, we must see ourselves as others see us if we are to achieve success.

CAUSE OR CHANCE?[1]

By Dr. PAUL R. HEYL
U. S. BUREAU OF STANDARDS

It has become almost a platitude to speak of the present period in physical science as one of iconoclasm. The past third of a century has called into question and modified or wholly discarded most of the theoretical principles which had been formerly regarded as permanently established. Matter itself has lost its individuality and has taken its place as but one more mode of manifestation of that Protean concept, energy. The doctrines of conservation of energy and of matter, once regarded as the twin pillars of the temple of science, have lost their separate validity and have become merged into one broader principle in which each supplements the defects of the other.

But we need not multiply illustrations. One by one the fundamental principles of nineteenth century science have suffered modification or displacement, though not without stout resistance occasionally on the part of some valiant upholder of the established faith. But, as time has shown, none of these champions has been any more able to withstand the advance of the Zeitgeist than was King Canute to stem that of the ocean.

It has been reserved for the past few years to attack what has always been regarded as the most fundamental principle of all. The absence of the usual opposition in this case is probably to be ascribed to the fact that the rank and file of science are not yet generally aware of the new mischief which their leaders are up to. Certain it is that whenever the attention of a small gathering has been called to the situation the expected antagonism has developed with a vigor proportionate to the esteem which has been universally accorded this last fundamental principle. I refer to a certain change of attitude of scientific philosophy with regard to the law of cause and effect.

I think it was Maxwell who compared the student of nature to a person in a room where there were a number of ropes dangling through holes in the ceiling. In pulling any of these ropes certain of the others would move up or down, and it was the business of the investigator to determine by experiments with the ropes the nature of the mechanism in the room above.

Notice that it was regarded as a foregone conclusion that there was such a mechanism, and that the observed motions of the ropes were not caused by somebody upstairs who took a malicious delight in tantalizing and perplexing the investigator below. In other words, scientific thought, even since anything worthy of the name has existed, has postulated a universe of law and order from which caprice or chance was totally excluded.

Such has always been scientific thought, but all thought has not always been scientific. Man has not always regarded nature as a realm of impersonal and unchangeable cause and effect. To the ancients the wind was the breath of Aeolus; the stormy waves of the ocean were caused by the wrathful strokes of Neptune's trident; and the heaving earth gave evidence of the displeasure of Poseidon, the earth-shaker. To primitive man nature was all caprice and no law.

This philosophy lasted long. Roger Bacon, the foremost (and almost the only) man of science of the thirteenth century, still accepted the old belief that the moon and the planets were carried about by angels. The scientific attitude has been one of slow growth. It crystallized into definite shape about the time of Newton, and is now old enough to have acquired somewhat of the authority of tradition.

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[1] Publication approved by the Director of the Bureau of Standards of the U. S. Department of Commerce.

Perhaps no other early work so well illustrates the definite shape which scientific philosophy assumed as Newton's Principia. The full title of this work is suggestive: "Mathematical Principles of Natural Philosophy." Newton assumed that all phenomena of nature could be reduced to mathematical principles, and actually went a long way toward completely proving this assumption, for he was able to reduce all phenomena of motion, whether celestial or terrestrial, to dependence upon the principle of universal gravitation.

That this doctrine fairly represented the current scientific thought of that day is evident from the acclaim with which the Principia was hailed by Newton's contemporaries. It was recognized that he had clearly set forth the antithesis between the old and the new, the abandonment of chance or caprice and the substitution of universal law. Since Newton's day natural law has been the prime article of scientific faith. Though there have always been phenomena which stood aloof for a time and resisted all efforts to bring them into line with the great scheme of things, these were regarded optimistically as unsolved problems, challenges to renewed endeavor. And as one by one many of these obstinate phenomena were subdued the belief grew stronger that law and order, physical cause and effect, were the very stuff of which nature was woven.

It is an illustration of the insatiable iconoclasm of the Zeitgeist that this fundamental principle of cause and effect has not escaped being called to the question, and it is a remarkable thing that such question should have come not from the anti-scientific but from the high priests of science themselves.

This latest skepticism concerns itself principally with the behavior of those recently discovered bodies, the electrons. The phenomena exhibited by these little bodies, the smallest known to us, have always been in some respects puzzling and incalculable, but scientific thought has been optimistic here also, confidently awaiting the ultimate victory. The essence of the new view is that the behavior of an electron is incalculable, not because the problem is as yet too complicated for us, but because, to state it baldly, the sections of individual electrons are not governed by the ordinary law of cause and effect. The new philosophy recognizes that where an individual electron may be at this moment is a matter of observation, more or less imperfect; it admits that where the electron has been in the past is a matter of history; but it asserts that where it will be in the future is a matter not for definite prediction but only of statistical probability.

This doctrine appears to strike at the root of all law and order, and yet, curiously enough, its protagonists recognize the existence of a kind of law on the large scale, but deny that it extends to individual units. The new philosophy is not such a complete reversion to primitive type as might be hastily concluded.

Perhaps the best illustration that we can give of this new thought is one based upon the behavior of units large enough to be familiar if not altogether comprehensible—human individuals.

The behavior of any individual under given conditions is, rigidly speaking, unpredictable. For your belief that I will react in a certain way to my environment you have nothing but a probability, perhaps a very high one, amounting to what you may consider a practical certainty, but never more than a probability. No one can say with absolute certainty that I will not, let us say, steal money during the coming year. It may be in the highest degree unlikely that I will, so unlikely that you may consider it insulting to harbor any suspicion of me, yet experience shows that occasionally an ordinarily well behaved man may do a most unexpected thing. While no one can say definitely just what you or I or he or she will do, yet with a million such individuals to serve as a basis for prediction it is possible to estimate just how many of them will depart from rectitude during the next year and how much money will be involved in the total sum. Such is the accuracy of this prediction that bonding companies risk their capital on it year after year, and make money. Individually, man is more or less of an enigma; in the mass he is a mathematical problem.

Something very like this is the essence of the latest turn of scientific philosophy. It asserts that the future behavior of a single electron is incalculable. We can not tell whether it will turn to the left or to the right, whether its velocity will be accelerated or retarded. All that we can say is that there is a certain percentage probability of any particular behavior, and that such a prediction is always verified by the result when a sufficiently large number of electrons is taken into consideration. In the electronic realm there is no individual causal certainty. Instead there is something which in a conscious organism we would call caprice. Dirac even uses the term "the free will of Nature." Yet as we pass from the individual to the crowd certain laws begin to appear, but they are no longer causal laws; they are only laws of probability.

Who are those who have adopted this strange way of thinking?

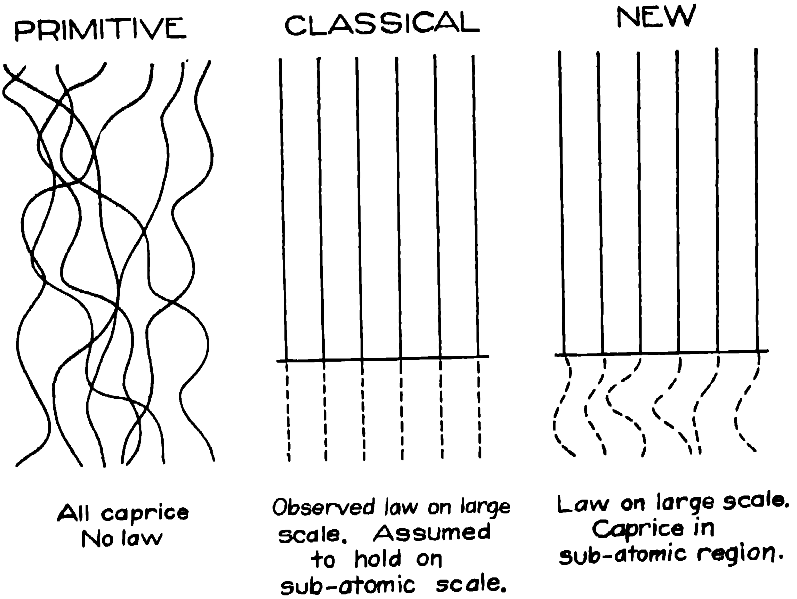
It must be said that there is an imposing array of authority on the side of this new thought—Bohr, Heisenberg, Dirac, Jordan, Born, Eddington, Bridgman and others have contributed in one way or another to its increase and diffusion. It must be assumed that such objections as occur at once to our minds must have occurred also to these recognized leaders, and before condemning the new philosophy *in toto* we should make an earnest effort to get the point of view of those who have been led to support it. It is therefore in order to ask the question which is the proper reaction of all scientific men to every new theory, no matter how bizarre—what is the evidence?

The evidence in this case is circumstantial and cumulative rather than direct and specific, but that is not necessarily a fatal objection.

Bohr began it. His atomic model was never satisfactory and no one was more keenly aware of this than Bohr himself. But he saw no way to improve it, and after much study of the subject he came to the conclusion a few years ago that the difficulties were fundamental, and committed himself publicly to the opinion that an accurate causal description of atomic phenomena on the basis of the classical frame of space-time was impossible.

About this time the new theories of wave and quantum mechanics came upon the scene. The wave-atom concept in particular excited a renewed hope that a causal explanation of atomic phenomena might be possible, but on further development it was found that the wave mechanics in its original form developed about as many new inconsistencies as it removed. When a theory thus runs into fundamental difficulties we have learned to take it as a hint from nature that we are on the wrong track, and that we must either discard or seriously modify our theory.

In the case of the wave-atom it was the latter course that was adopted. The wave concept has been so radically modified that nothing but its outer form is left. De Broglie, the founder of the wave mechanics, expresses this change


PRIMITIVE
CLASSICAL
NEW
All caprice
No law
Observed law on large scale. Assumed to hold on sub-atomic scale.
Law on large scale. Caprice in sub-atomic region.

by saying that the Schrödinger wave is no longer to be regarded as a physical entity, a vibratory phenomenon actually taking place in space, but merely as a symbolic mathematical representation of the positions and states of motion of the separate electrons. The square of the amplitude of the wave at any point, formerly visualized as the intensity, is on the new view nothing but the numerical measure of the probability that an electron will be found at that point. This converts wave mechanics into quantum mechanics, and therefore E. L. Hill, in the "Editor's Column" of *Physics* for December, 1931, suggests that the term wave mechanics should be dropped altogether.

Such an interpretation of the wave equation of Schrödinger puts us in this position: the solution of the equation gives us not a definite state of motion at a certain point and time, but in its stead a probability function. This change of base avoids certain difficulties inherent in the older wave concept, and gives the theory a new lease of life.

The perspective of the situation is something like this: in attempting a causal and individual explanation of atomic phenomena we have always sooner or later run up against a stone wall. The alternative line of statistical probability avoids this barrier, at least for the present. The successes of the quantum mechanics have been many; no end is yet in sight, and with each success the cumulative force of the evidence increases. Thus on the principle of driving a nail where it will go our line of thought is shaped for us by nature herself.

The first impression which this new doctrine makes upon one trained in the old school is that it is a hasty cutting of a Gordian knot which, with a little more time and patience, might have been untied. The case of the kinetic theory of gases comes to mind in this connection. Out of the apparently random motions of the molecules of a gas there may be deduced certain statistical laws but further study of these seemingly fortuitous motions leads to a causal explanation in terms of mutual collisions, phenomena of an order more fine-grained than those with which the statistical laws are concerned. Similarly, in the human analogy, it is possible to argue that the behavior of an individual is not due to free will as he likes to suppose, but is a consequence of causal reactions in his brain cells of an order so fine grained and recondite that we are not yet able to follow them. May it not be possible that the apparently lawless behavior of individual electrons is due to causes hitherto unrecognized, and on a scale proportionately fine-grained?

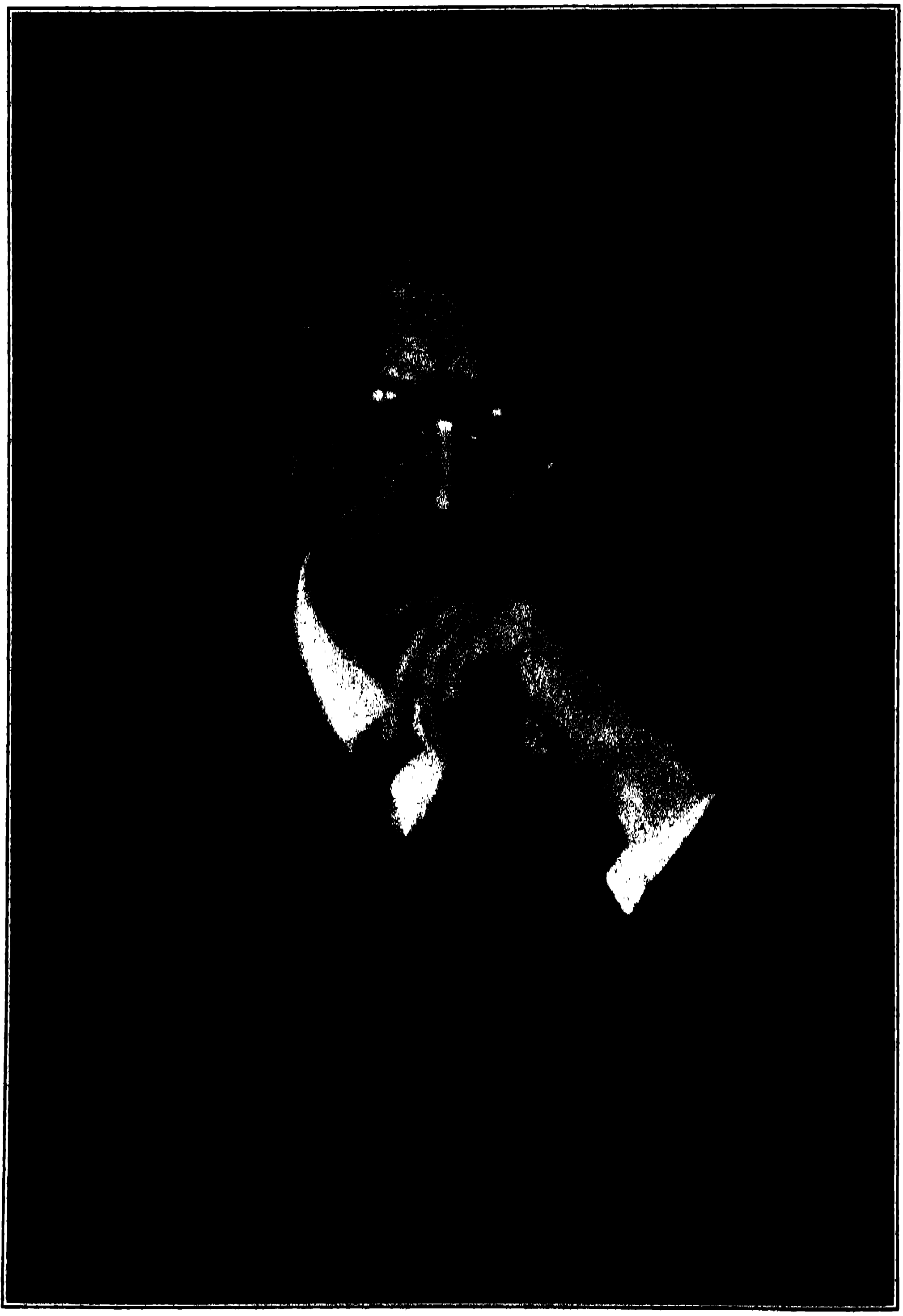
To this objection the upholders of the new make the following answer. The element of incalculability in electronic behavior is not, as might be supposed, entirely a matter of human limitations. There is reason to believe it to be a fundamental characteristic of nature herself, but which from its magnitude becomes perceptible only on an atomic or sub-atomic scale. This is why it has been only recently recognized. This newly discovered characteristic has been formulated in Heisenberg's principle of indeterminacy.

This principle has become familiar, at least in name, to most physicists, but there seems to exist a rather general misconception of it. Many suppose that it states nothing more than our inability to make accurate observations because of the disturbances introduced by the measuring apparatus. Were this all, the principle would be neither new nor worth serious consideration. The vital feature of the principle is not the disturbance of the thing measured, but the fact that there is something essentially incalculable about this disturbance, so that it is inherently impossible to allow for it completely. We can not estimate the magnitude of the interference caused by the observing apparatus more closely than within certain limits which do not depend at all on instrumental or subjective imperfections, but upon something as fundamental and objective as Planck's constant of action.

As the situation presents itself we appear to have two alternatives. We may assume the behavior of electrons to be causal, the unrecognized causes operating being on a scale perhaps as fine-grained in proportion to the electron as those which govern human actions are to our own scale of magnitude. In other words, we may take a deterministic view of nature. On the other hand, we may take the free will position with regard both to man and to the electron, denying causal laws and admitting only statistical laws of probability. It would seem hardly fair to lay the flattering unction of free will to our own souls and deny it to the electron. And if free will is a satisfactory working hypothesis on the scale of our own highly complex organism, which depends ultimately on electrons or something still more fundamental, why should it be unthinkable for a free lance electron?

The situation has been well summed up by de Broglie in one of a collection of essays entitled "Receuil d'exposés sur les ondes et corpuscules," from which I quote the following sentences.

> Causal laws replaced by laws of probability, physical individualities well localized and of well defined movement replaced by physical individualities which refuse to let themselves be simply represented and can never be more than half described: such are the surprising consequences of the new theories. In digging under these laws of probability, shall we succeed in re-finding causal laws as we have found recently behind the statistical laws of gases the causal laws of the movement of molecules? Certain arguments would lead to this belief, but it would be indeed imprudent to assert it.
>
> What we have said suffices, we think, to show the importance of the change in the point of view which has recently taken place in physics. Whatever may be the final fate reserved for these new doctrines, it is of infinite interest to philosophers that physicists have been led, even though but for the moment, to doubt the determinism of physical phenomena and to question the possibility of describing them in a complete fashion within the frame of space and time.



DR. CARL BOSCH

THE PROGRESS OF SCIENCE

THE AWARD OF THE NOBEL PRIZE IN CHEMISTRY TO DR. CARL BOSCH AND DR. FRIEDRICH BERGIUS

The Swedish Academy of Sciences, in awarding, on December 10, 1931, the Nobel Prize to the two German chemists, Professor Carl Bosch and Dr. Friedrich Bergius, has bestowed this high international honor upon two men whose labor has resulted in the most conspicuous economic achievements of technical chemistry in the last twenty years.

The name of Bosch stands, first and foremost, for the technical development of the high-pressure industry, for the adaptation of Haber's invention—the catalytic high-pressure ammonia synthesis—to large-scale production of artificial fertilizers from atmospheric nitrogen.

Bergius was the first to show that it was possible to crack coal under addition of hydrogen so as to obtain liquid products. His process was running on an experimental scale when, in 1924, his patents were taken over by the Badische Anilin- und Sodafabrik, which had been working on the same problem for some time.

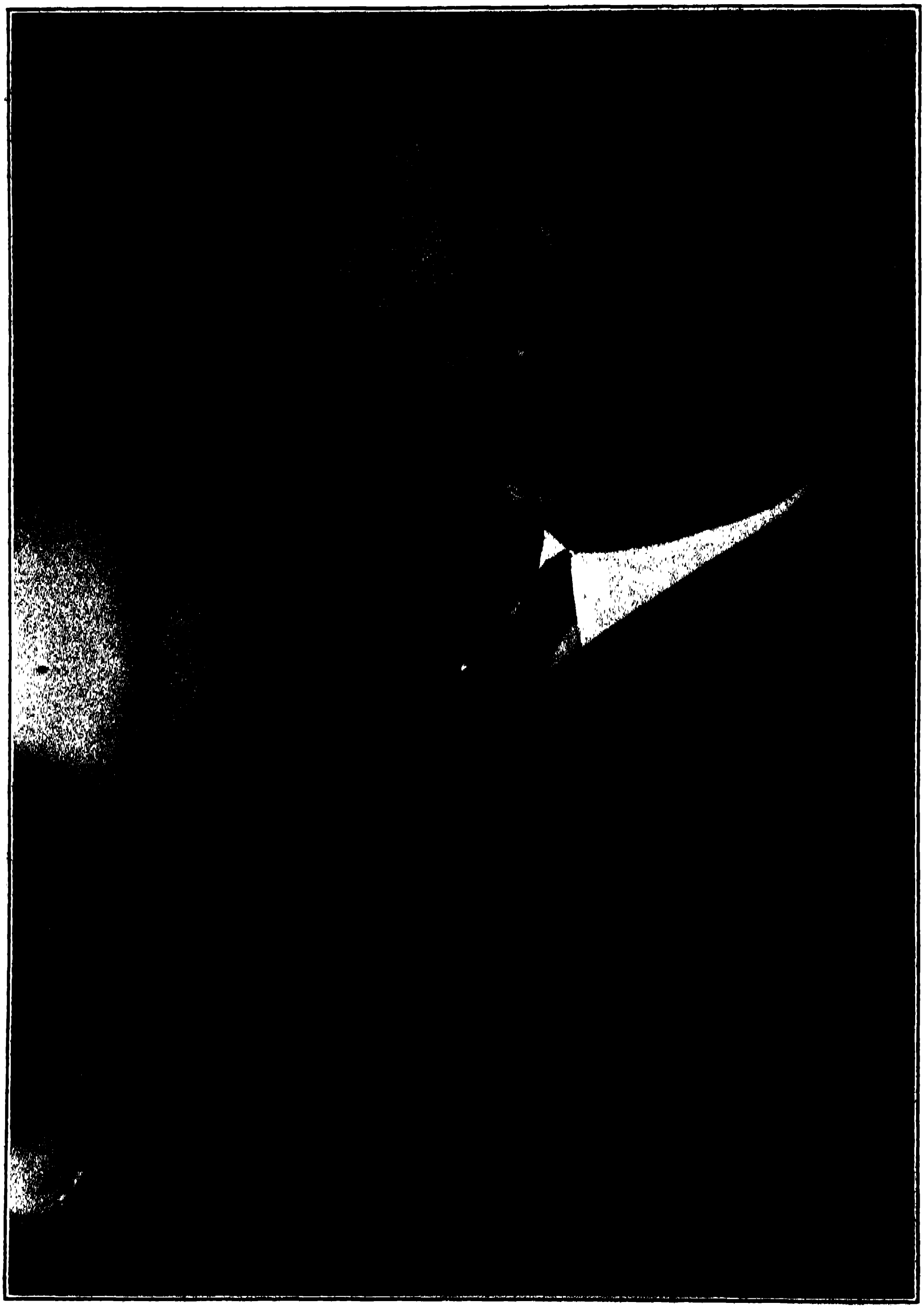
The "Badische," then under the direction of Bosch, basing upon his experience in high-pressure techniques and using catalysts, carried the hydrogenation process to a technical success, not only in its application to coal and tar-oil, but also to natural oil. Especially as applied to mineral oil, hydrogenation is a marked success in respect of both technical perfection of refinery and adaptability to the demands of the market.

If we undertake, in a narrow frame to draw a picture of the two men, we must confine ourselves mainly to one side—their development and their successful working in the service of chemical technology.

Carl Bosch was born in Cologne, on August 27, 1874. At an early age, working whenever he could in his father's installation workshop, he acquired considerable dexterity in metal working and fine mechanics, perfecting this skill by one year's practice in the Marienhütte, Kotzenau, Silesia. In 1894, he went to the Charlottenburg School of Technology for the study of engineering and metallurgy. Two years afterwards, however, he went to Leipzig University, devoting himself entirely to chemistry. He was graduated under Professor Wislicenus, his thesis being: "Über die Kondensation von Dinatrium-Acetondicarbonsäurediäthylester mit Bromacetophenon." His fellow-students at the time praised his manual skill, as, for instance, in glassblowing. Just before the beginning of a lecture, a Röntgen-tube broke; nobody knew what to do, but Bosch repaired it just in time.

In 1899, Bosch entered the service of the Badische Anilin- und Sodafabrik, Ludwigshafen on Rhine. Under the auspices of Dr. Knietsch who employed him in the phtalic and sulfuric acid factories, it was his good fortune to come in close touch with the then fast rising industry of synthetic indigo. Here, his sound training in handicraft, his constructive ability and his wide knowledge of materials found full scope. While engaged upon problems of thermal economy, he discovered improvements, constructing, for instance, a new type of producer to gasify lignite briquettes. It is largely due to his advocacy that at that time coal-heating was superseded by gas-heating, and that gas-engines were installed for cheap motor power.

Soon after 1900 he took up nitrogen fixation which then began to agitate the



DR. FRIEDRICH BERGIUS

minds. He first chose the way via the metal cyanides and nitrides at that time considered the most practicable. In 1907, he put up a trial factory for the manufacture of barium-cyanide according to the Margueritte and Sourdeval process. At the same time he took an important part in the technical development of the Schönherr arc-light process then carried out by the Badische Anilin- und Sodafabrik in Norway.

However, it was not until the "Badische" took over Haber's ammonia synthesis that his abilities developed to the full. He was entrusted with the technical adaptation of the process to large scale operation. Much has already been written about this immense task and its stupendous success. We therefore confine ourselves to a few particularly conspicuous features.

Bosch early recognized that a large-scale industry could not possibly be built up upon osmium and uranium which Haber had found to be the most active catalysts. He and his collaborators looked round for a cheap, easily accessible, contact substance, and right from the beginning he suggested iron on account of its relatively complicated spectrum. With the experience gained in the nitride experiments, they soon succeeded in preparing iron, at that time considered inactive, in such a way as to make it a highly suitable catalyst.

The novel, extremely difficult, constructive requirements conditioned by the adaptation of the high-pressure synthesis from the laboratory scale to a large technical scale, stimulated his inventive faculties. One particularly characteristic example deserves remembrance. In the initial stages of large-scale operation there was not, as yet, the necessary experience to cope with the problem of high pressure combined with high temperature, essential features of the process. It soon showed that the hydrogen diffused through the steel, dissolving its carbon content, thus destroying the strength and tenacity of the pressure pipes. The expensive high-pressure furnaces, soon after they were started, cracked and became useless. There seemed to be no alternative but making the furnaces still more expensive by lining them with silver and gold. One day Bosch surprised with the simple ingenious suggestion to line the pressure-bearing mantle with an easily exchangeable iron tube to bear the attack of the hydrogen. As a protection against the diffused gas the mantle itself was fitted with small holes through which the hydrogen could escape into the open air. This difficult problem was solved.

How far-seeing Bosch was, with regard to the future development of the Haber synthesis, and how optimistic right from the beginning, became manifest by his answer to the question as to how large he thought the high-pressure furnaces would become in the end: "We shall go to the very limit of the German steel industry's capacity!" This at a time when cast-steel blocks were already being made weighing 100 tons.

When the problem of the manufacture of ammonia was solved there followed the second, equally difficult, task of converting the ammonia obtained into valuable marketable products such as nitric acid and fertilizers. Also here Bosch's chemical and technical skill triumphed. Oxidation of ammonia to nitric acid in large furnaces by means of the newly found iron-bismuth catalyst; synthesis of urea from carbonic acid and ammonia; increasingly effective fertilizer salts of all kinds up to the numerous mixed and complete fertilizers—a bulk of patents give evidence of the abundance of his inventive genius.

The crowning of his labors are the two immense nitrogen-works of Oppau (1913) and Leuna (1917).

Yet, his furtherance of the high-pressure industry did not cease even when, on being appointed director-in-chief of the Badische Anilin- und Sodafabrik in 1919, and president of the I. G. Farbenindustrie Aktiengesellschaft in 1925, he was compelled to occupy himself more and more with problems of organization and economics. His influence is to be felt in the subsequent stages of development not only of the nitrogen industry, but also of the methanol-synthesis and finally the catalytic hydrogenation of coal and oil.

The picture of Bosch as a natural scientist and technologist would be incomplete without a few lines as to his other scientific interests that fill his leisure hours and afford him the necessary recreation. If not constructing a new apparatus in the workshop of his home at Heidelberg, or investigating astrophysical problems in his private observatory, he most likely sits over beetles and plants, or works in his private research laboratory on an old favorite subject—the physical chemistry of rare metals. His interest in the progress of theoretical physics—and his profound knowledge of its very latest achievements, the theory of relativity and the mechanics of quanta—has secured him the friendship of such famous physicists as Einstein and Nernst.

Friedrich Bergius was born on October 11, 1884, at Goldschmieden, Silesia, where his father was director of a chemical factory. He studied at Breslau, Leipzig, and Karlsruhe, was graduated in 1909 at the School of Technology, Hannover. There he maintained a private research laboratory, investigating the effect of high pressure upon chemical reactions, especially in connection with the genesis of coal.

In the course of experiments on the action of water upon coal under high pressure and at high temperatures, the question arose for him whether in cracking coal or lignite it was possible to add hydrogen so as to obtain liquid hydrocarbons. He actually was the first to succeed in getting from coal, by adding hydrogen, products very much like low temperature tar or crude oil and, in the same way, light oils from heavy oils.

The first patents relating to the hydrogenation of coal Bergius obtained in the year 1913 while still working at the School of Technology, Hannover. His subsequent experiments were carried out at Goldschmidt's laboratories at Essen, later on at Mannheim-Rheinau in a plant specially built for his purpose.

The difficulties that Bergius had to struggle against resulted, as in the ammonia synthesis, largely from the combination of high temperatures and high pressure. On attempting large scale operations, however, unprecedented difficulties arose. Pulverized coal in the form of a thick paste had to be pumped through the high pressure apparatus, and pipes and vessels became stopped up, the pumps clogged, and the wear and tear was enormous. Entirely new apparatus had to be invented, and entirely new materials had to be found. Tenacious and ingenious, Bergius did his best to overcome these difficulties, and much progress in the technology of high pressure is due to his efforts.

Though his patents are fundamental the hydrogenation process took the decisive direction only when in spite of all doubts that had been uttered with respect to the poisoning character of the crude materials involved, the I. G. Farbenindustrie Aktiengesellschaft applied catalysis.

An outstanding characteristic of Bergius is his wealth of inventive ideas and his unceasing activity that impels him to keep in quest of the new.

At the convention held by the Association of German Chemists in 1928, Bergius presented the results of 14 years' labor in a new field of research: the chemical utilization of wood. Following up Willstaedter's research work on the hydrolysis of wood, he succeeded in working out a simple technical process of converting, by means of hydrochloric acid, the indigestible (cellulose) substances of the wood into digestible carbohydrates, thus obtaining from waste wood a valuable fodder. Though the process has, as yet, no practical importance for agriculture, it is not unlikely that under changing conditions it may become a commercial proposition.

Bergius' personality is not easily gauged from a merely casual meeting. Most people who have become acquainted with him in social intercourse see in him the man of esprit and the man of the world, the generous patron of the arts and sciences. Yet, this is only one aspect of him. Behind his apparent ease and suavity there is however an extremely serious and diligent worker who tackles problems with unimpeachable logic and a rare tenacity of purpose.

It deserves to be mentioned that Bergius who has contributed much to science has, whenever possible, largely contributed also to the furtherance of scientific institutes, and the research organization he created has been maintained by him even in times of adversity and at great financial sacrifice.

That Bergius has avoided academic ties and industrial association is attributable not only to his love of freedom; he, no doubt, clearly realized that his faculties found the necessary scope only in complete independence.

Yet both Bergius and Bosch have received public recognition, universities have made them honorary doctors, prominent societies honorary members. These and many other distinctions have now been crowned by the Nobel Prize.

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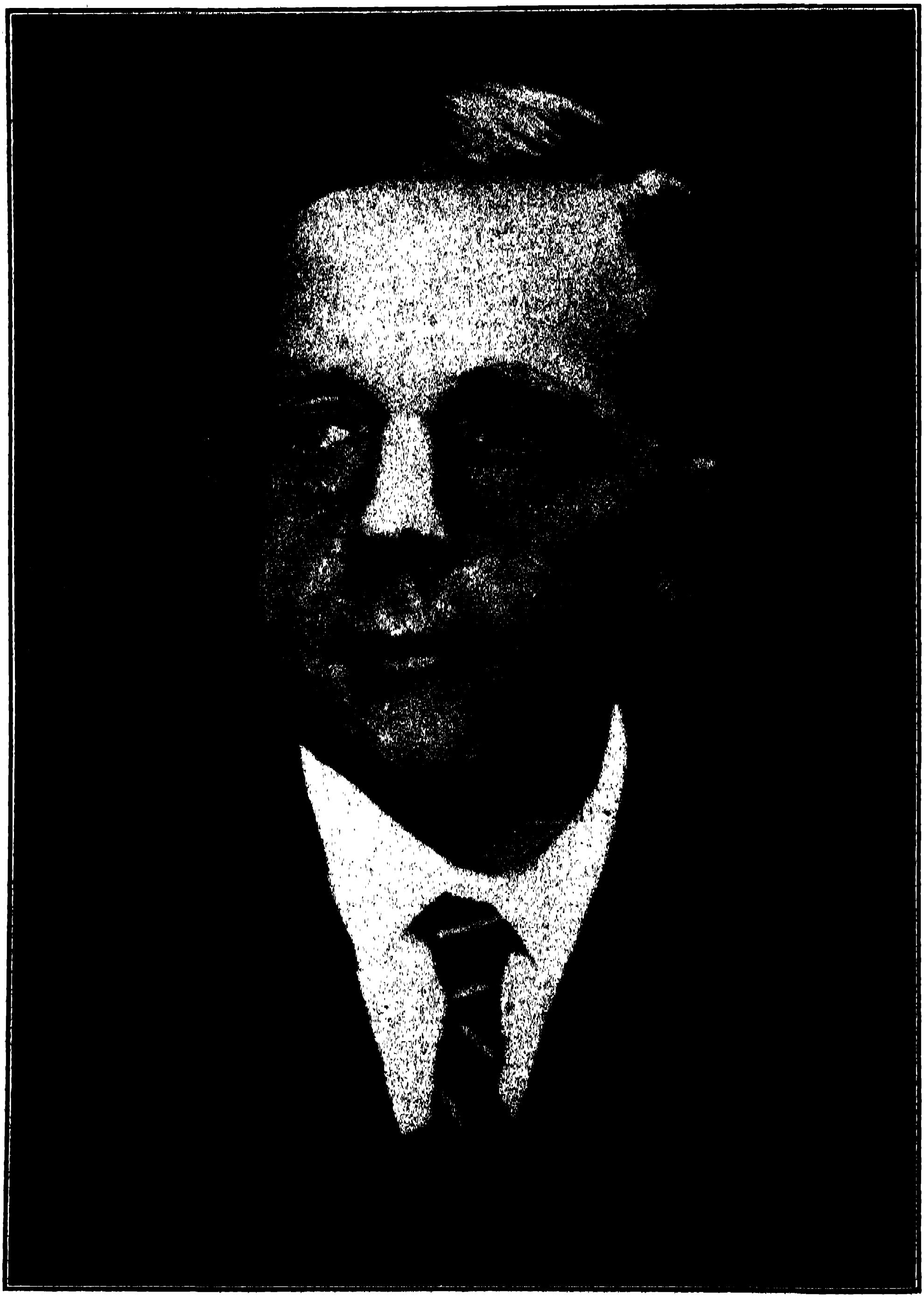
PROFESSOR OTTO WARBURG, RECIPIENT OF THE NOBEL PRIZE IN MEDICINE

PROFESSOR OTTO WARBURG who was awarded the Nobel Prize in medicine for 1931, published his first investigation of cellular respiration twenty-four years ago. Since then there has come from his laboratory a copious flow of papers on this subject, and on other processes by which energy is supplied to the cell. A first glance at the titles of his papers shows that many of them have been on fertilization, photo-synthesis, cancer, nitrate reduction by bacteria and on other apparently unrelated phenomena. Closer study reveals the fact, however, that in all these investigations Warburg's thought was directed toward investigating the energy-producing processes of the cell, and especially toward respiration. It is difficult for us to perceive how Warburg first arrived at this point of view, maintained throughout all his work, for, curiously enough, before his paper of 1908 he had spent several years in research on organic chemistry in Emil Fischer's laboratory. And yet it is not organic chemistry, but rather the physiology of Lavoisier and Pasteur that forms the background of Warburg's contributions.

The experimental methods employed by Warburg combine simplicity and elegance with imaginative daring, so that his work possesses a kind of beauty rarely achieved in chemical physiology. These qualities were developed gradually over a period of twenty years. They developed only in response to the needs created by an ever-deepening insight into the nature of the problems studied. One characteristic of Warburg's experimental procedures was present, however, from the very beginning of his investigations. His methods, by never causing a permanent injury to cells, made possible the study of normal respiration. One way of avoiding injuring the cell



PROFESSOR OTTO WARBURG

was (as many other investigators have done) to select for his experiments red blood cells or unicellular organisms, such as sea urchin eggs, yeasts, bacteria and algae. Being eager to extend his studies to the tissues of higher animals, he boldly conceived the idea of cutting thin slices of tissue, so thin that simple diffusion suffices for the transport of materials between the cells of the tissue and the fluid in which the piece of tissue is suspended. It seems scarcely credible that the respiration of a thin slice of tissue could proceed at the same rate as it does in the same tissue in its normal position in an organ. And yet direct experiments (by other investigators) have shown that the rates of respiration in the two, excised and intact tissues are the same. Previous methods of measuring the respiration of isolated tissues involved the use of rather thick pieces of tissue, in which diffusion between tissue and surrounding medium was inadequate for the needs of the cells; or of tissues which were finely minced, so that their cells were seriously injured.

Even after one has acquired a mastery of the methods of measuring the respiration of isolated cells and of excised tissues, how is the chemical mechanism of respiration within the living cell to be analyzed? Substances which are stable when exposed to oxygen outside the organism, in cells of the organism are burned by oxygen readily. There must, therefore, be catalysts in the cells which speed up oxidations. To investigate these catalysts Warburg turned to one of the old methods of physiology—to the use of poisons. In his hands this method became the most precise and powerful technique of chemical physiology. Poisons that do not injure the cell irreversibly and which have a highly specific inhibiting action can be used chemically to probe, as it were, the catalysts within the cell. The next step is to discover how the poison inactivates the respiratory catalysts. This can be learned by constructing a relatively simple oxidizing system in a test tube on which the inhibiting action of the poison can be imitated. The analogy between the systems *in vivo* and *in vitro* is then made as exact as possible, and if the nature of the catalyst inactivated *in vitro* is known, it is inferred that the same catalyst is present *in vivo*. Study of the system *in vitro* can also provide clues for a more direct investigation in the cell. The success of the inhibitor technique depends upon the use of a poison which is highly specific, which can in fact act on only one type of catalyst.

Early in his studies Warburg came to the conclusion that iron acts as an essential respiratory catalyst. This conclusion depended on the observation that on the one hand respiration can be inhibited reversibly by minute concentrations of cyanide or hydrogen sulfide, while heavy metal compounds can catalyze *in vitro* the oxidation of biological substances, but become catalytically inactive when combined with cyanide and hydrogen sulfide. The heavy metal active in the cell was supposed to be iron because iron is the heavy metal present in tissues in the highest concentration. Experiments with cyanide and hydrogen sulfide failed, however, to fix the precise nature of the heavy metal compound. At first the inhibitors used were not specific enough in their action and, furthermore, the evidence was based entirely on analogy.

Warburg's next step was the discovery that tissue respiration may be inhibited completely and reversibly by carbon monoxide. It had long been known that when small concentrations of carbon monoxide are inhaled by vertebrates, poisoning ensues. Claude Bernard in 1883 discovered that carbon monoxide acts by combining with hemoglobin and by so doing renders red blood corpuscles unfit to transport oxygen to the tissues.

Animals which do not depend on hemoglobin for this function are not influenced by low concentrations of carbon monoxide. Higher concentrations, however, of carbon monoxide were found by Warburg to inhibit the respiration of all living tissues, plant as well as animal. When carbon monoxide combines with hemoglobin it does so with the pigmented part of the molecule. This pigment is an iron-porphyrin complex. Warburg was, therefore, led to suppose that it must be an iron-porphyrin complex which exists in all respiring tissues, where it acts as a respiratory catalyst or enzyme. The evidence for this belief depended on the observation that iron-porphyrin compounds can catalyze oxidations *in vitro*, but that when these compounds are combined with carbon monoxide they are catalytically inactive. The analogy between the behavior of the iron-porphyrin catalyst in the test tube and the respiratory catalysts present in the cell is made much closer by studying the action of light on the two systems. It had already been discovered by J. S. Haldane that the combination between hemoglobin and carbon monoxide is dissociated by light. Warburg now found that by the action of light the inhibitory effects of carbon monoxide on tissue respiration is abolished. The manner in which carbon monoxide inhibits tissue respiration suggests strongly, therefore, that it is an iron-porphyrin compound which acts as a respiratory catalyst in living tissues.

At this point the method developed by Warburg becomes so much more precise that the nature of the respiratory ferment inactivated by carbon monoxide can be clearly and decisively demonstrated. The part of his procedure which yields an entirely new kind of information is spectrum analysis, for this permits the demonstration not only that the respiratory ferment has some peculiar properties also possessed by iron-porphyrin compounds but that the respiratory ferment definitely is an iron-porphyrin compound. Light of one color is more effective in influencing the carbon monoxide inhibition of respiration than light of another color. This means that the carbon monoxide compound of the respiratory ferment is a pigment which absorbs one kind of light more than another. Suitable quantitative experiments on the effectiveness of different kinds of light permit the calculation of the precise extent to which the carbon monoxide compound of the respiratory ferment absorbs different kinds of light or, in other words, the calculation of the ferment's spectrum. The spectrum found is that of an iron-porphyrin compound. No substance can have this spectrum, regardless of how it can react with carbon monoxide or any other inhibitor, unless it has an iron-porphyrin molecular structure.

When one considers that the iron-porphyrin ferment of respiration is present in one part only in a hundred million, it is remarkable that its existence has been discovered. Isolation of so minute an amount of ferment seems out of the question. And ordinary analytical methods of chemistry do not permit the identification of the nature of so small amounts of a substance even if it can be isolated. Fortunately, the actual measurement of the ferment's spectrum by the carbon monoxide inhibitor technique depends on the results of the presence of the ferment which are great, despite its small concentration. The demonstration of the iron-porphyrin nature of the respiratory ferment is all the more striking when one considers that until Warburg's investigations the chemical nature of no other intracellular enzyme present in minute amounts was known, and that extremely little is known about the normal function even of the ordinary, well-studied constituents of the cell which are present in large amounts.

Due to Warburg's researches more is

now known about the function of the iron-porphyrin ferment than about any other factors in cellular respiration. It should be remembered, however, that this ferment is only a part, though an essential part, of the respiratory system of the cell. Ordinary oxygen does not in fact react directly with the foodstuffs within the cell. It acts indirectly by combining first with the iron-porphyrin ferment, but whether oxidized iron-porphyrin ferment acts directly on the metabolites is unknown. There are probably additional intermediary ferments. It is known that the foodstuffs, or metabolites, are converted, furthermore, into readily oxidizable forms. Metabolites, as well as oxygen, require "activation." The complexity of the system probably makes possible that regulation of activity in response to the needs of the cell so characteristic of living systems.

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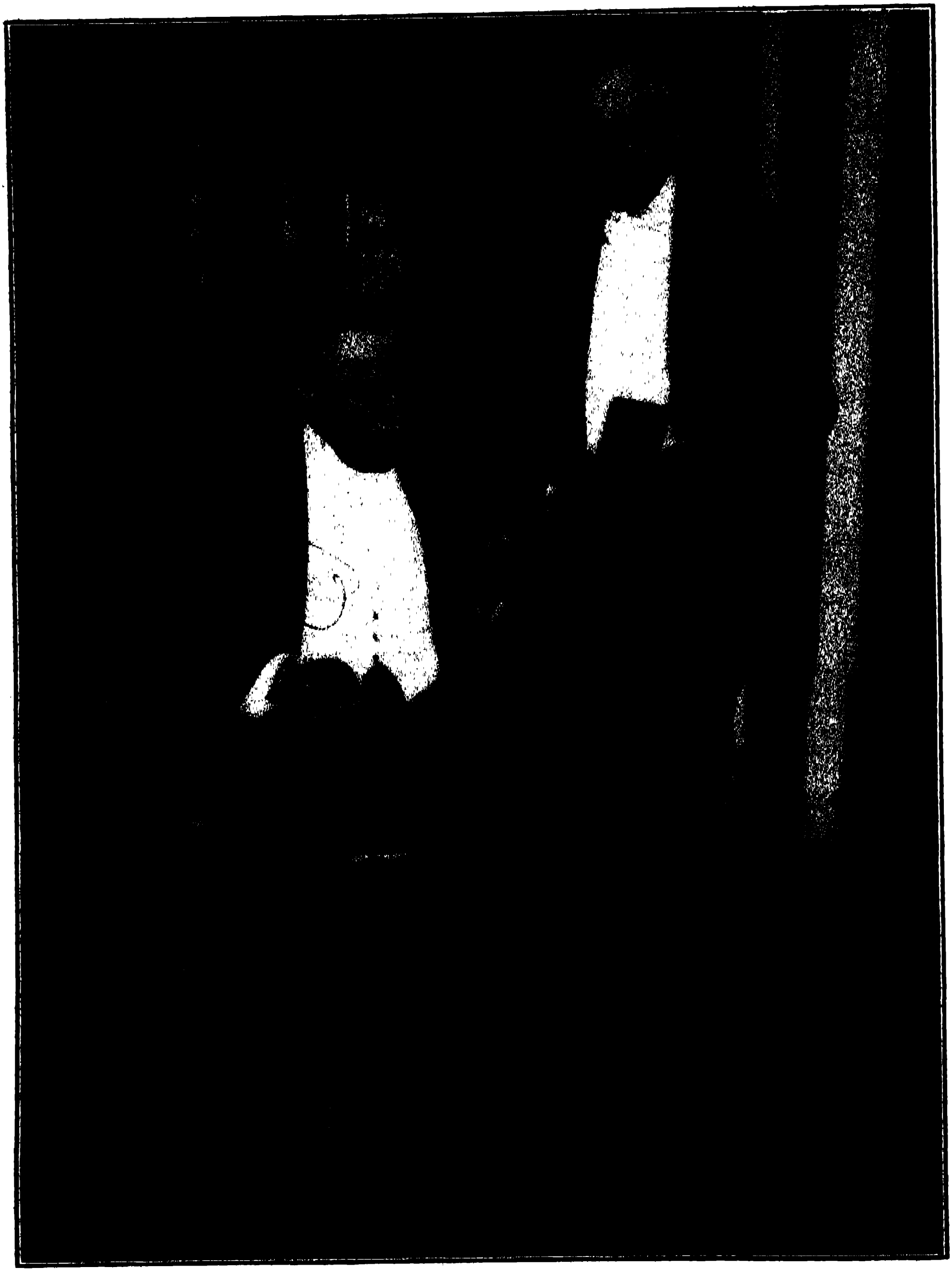
THE AMERICAN INSTITUTE OF PHYSICS

As the science of physics has developed and its applications have increased in importance, specialized groups have necessarily grown up. While the result has been the further progress of such special interests, something of the inherent unity of physics has been lost sight of. In a very general sense a unifying step now seems decidedly called for. There have appeared, moreover, several immediate specific problems which can only be attacked adequately with the whole support of all who are interested in physics. One of these is considered to be of the most immediate importance, and it is the pressing nature of this particular problem that has supplied the necessary driving force for the initiation of the movement which this article describes.

To meet the generally recognized need for an agency suitably constituted to undertake cooperative projects, the American Physical Society, the Optical Society of America, the Acoustical Society of America and the Society of Rheology have formed the American Institute of Physics. This new organization is controlled by the four societies and certain specific tasks have been outlined for its first efforts. It does not have individual memberships at the present time, and its constitution is still in process of development. On the other hand, its first tasks are definitely set.

The four societies publish seven journals all more or less technical in character. They are the *Physical Review, Review of Modern Physics, Physics,* the *Journal of the Optical Society,* the *Review of Scientific Instruments,* the *Journal of the Acoustical Society,* and the *Journal of Rheology.* With perhaps one exception these journals are projects which the societies find increasingly difficult to support, yet they are vitally necessary publications. This situation was brought to the attention of The Chemical Foundation, whose financial assistance in publications of a scientific character is well known. In conference it was recommended that a cooperative organization, representative, so far as possible, of all physics, should be formed at once, and the material help of The Chemical Foundation in such a project was promised.

A cooperative committee of the four societies was formed, and this has now become the Governing Board of the American Institute of Physics. It consists of three representatives chosen by each society, making a board of twelve in all. The initial personnel is as follows: Physical Society: Karl T. Compton, Chairman of the Board; George B.



RECIPIENTS OF ENGINEERING HONORS

Professor M. I. Pupin, of Columbia University, who recently received the John Fritz Gold Medal awarded jointly by the four national engineering societies, and Dr. E. W. Rice, Jr., of the General Electric Company, who was given the Edison Medal by the American Institute of Electrical Engineers.

Pegram, Secretary; John T. Tate. Optical Society: Paul D. Foote; Loyd A. Jones; F. K. Richtmyer. Acoustical Society: H. D. Arnold; Harvey Fletcher; F. A. Saunders. Society of Rheology: E. C. Bingham; Wheeler P. Davey; A. Stuart Hunter.

It is at present contemplated that each member shall serve three years, a new representative to be elected to replace one retiring each year by each society.

At a meeting held at Schenectady in September the board appointed the writer to act as Director of the new institute. Dr. John T. Tate, professor of physics, University of Minnesota, who is editor of the journals of the Physical Society, was appointed adviser on publications.

The office of the American Institute of Physics was opened in October at 654 Madison Avenue, New York, N. Y., rooms in the office of The Chemical Foundation being made available for this purpose. Work commenced at once under three headings, namely, publications, organization and public relations.

PUBLICATIONS

The first task is to study the financial problem, gathering data concerning subscriptions, number of pages, printing costs, etc. The second is to evolve a plan of reorganization which will ensure the services of the publications to the members according to the same high standards as at present and at the same time effect pronounced economies. It is too early to say in detail how this may be done. It can be said, however, that there is no thought of taking the editorial direction of the journals out of the hands of the societies. It is recognized that an editor appointed by and acting for each society must have complete authority to decide what material is to be printed.

There is, on the other hand, no reason why each society should burden itself with the business of subscriptions, advertising, printing and mailing. To do all this similar business for the seven journals in one office would be to adopt recognized economic business principles. There would be a saving of time and money and probably an increase in efficiency. The institute would become a publishing agent for the societies. It would have the strength of the combined circulations of the seven journals in negotiations with printers and advertisers, obviously to the advantage of the journals. The institute will work out the details of a plan embodying these features and submit the plan to the societies.

ORGANIZATION

The committee which organized the institute realized that other groups beside the four societies they represented were interested in the movement and should be associated with it. The new American Association of Physics Teachers is one of these, and it is hoped that when this association is in full operation it will likewise participate in the responsibilities and services of the institute. There are other national and local groups, some very active, of persons interested in physics and its applied branches. It is regarded as very desirable to enlist the interest of these groups in the institute and to make the institute of service to them. A large number of suggestions in this direction have already been made and these are being carefully analyzed as to desirability and feasibility. The problem is a large one that has been growing up for years and naturally it can not be solved in a few months. A great deal of caution must be observed, moreover, in initiating new ventures at a time when financial support is hard to find. It often turns out also that a demand for a particular project does not have behind it the support of the numbers that its vehemence indicates. Thus any service—such as a publication—which may be contemplated must be limited to such features as are fairly certain to attract a wide approval. The officers of the institute are conferring with local groups with the object of isolating such features.

PUBLIC RELATIONS

In the progressive world of the present day, science has become the center of an increasingly broad and enlightened public interest. In the words of one of the editors of *The New York Times* "Science is news—front page news!" It is recognized that to-day's discoveries in the fundamental sciences may have more effect on the future of the human race than the rise and fall of governments or of economic institutions. It becomes the duty of the scientist who lives as an integral part of to-day's world to keep the public informed accurately and fully of those developments which bid fair immediately or indirectly to alter the general environment.

It is also well known that newspapers and popular periodicals are a tremendous medium for education. The scientific world should use this medium for the broader dissemination of knowledge.

With all the public appreciation of fundamental science, however, there is an astonishing lack of realization that in inanimate nature the fundamental science is physics. Chemistry is everywhere known for what it is. In its applications, physics, on the other hand, is not known as physics. It is known as engineering. Many laymen do not know that radio, refrigeration, sound motion pictures, etc., are physics. Hence the recognition which these innovations should have brought to physics has been lost. The result has been that many grants and bequests for research which might have come to physics have been used in less fundamental, even though still worthy fields. Also a man calling himself a physicist has been something not understood—perhaps "a kind of chemist"—and by virtue of the uncertainty has found that his profession did not provide for him an economic security appropriate to his ability.

The American Institute of Physics is undertaking a study of the relation between science and the press. It proposes to prepare for the papers suitable accounts of the research activities of the members of the societies and the proceedings at the meetings. It has already been found that the science reporters of the papers will cooperate whole-heartedly in such a program. It may be confidently expected that the ultimate result will be an improvement in the status of the physicist.

CONCLUSION

The very multitude of tasks already presented or proposed to the institute is a convincing evidence that here is a development brought about by the pressure of real forces and that its existence is a real necessity. It is not a result of misguided ambition to start something new, and it is free from any element of artificiality. In the manner that a research tool, like the vacuum tube, created for a specific scientific purpose, is likely to open up new fields of research, the institute may go far in the future development of physics. Certainly further applications of this cooperative research tool will be found. It depends, like any other human activity, upon the continued active and loyal support of those who want it. In the meantime its further development should be steady and well founded rather than rapid.

HENRY A. BARTON

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APRIL, 1932

DEMOCRACY AND DEPRESSIONS[1]

By Dr. WILLIAM B. MUNRO

PROFESSOR OF HISTORY AND GOVERNMENT, CALIFORNIA INSTITUTE OF TECHNOLOGY

DEMOCRACY makes its poorest showing in emergencies. Its merits, such as they are, appear most clearly in times of peace and economic prosperity. In such eras the problem of keeping people satisfied with their government is never a serious one. Prosperity silences criticism. It constrains the voters to approve any kind of leadership or no leadership at all. But when a country stands with its back to the wall in wartime, or when its industrial system is in serious danger of collapse, then the shortcomings of democracy as a governmental device become all too apparent, and a spirit of impatience spreads among the masses of the people.

Throughout the countries of Europe the democratic form of government has been losing its hold on the confidence of the people during the past ten years. Much of the popular enthusiasm for it, which surged forth at the close of the war, has now disappeared. It is being assaulted from the Left flank by Communism, and from the Right by Fascism. Save in Russia and in Italy, the foes of democratic government have not yet triumphed, but they are gaining ground in other countries. No one need be surprised to see Germany go Fascist or Spain go Communist if the economic situation which is giving rise to bitter discontent in these two countries is not alleviated. Even in England the traditional system of ministerial government has been severely jolted by a coalition cabinet which, in openly discarding the principle of solidarity, has made the government a house divided within itself. It is difficult to see how the British system of responsible executive rulership can permanently function under such an arrangement. Only in France, among all the leading countries of Europe, does the democratic structure stand unimpaired by the happenings of the past few years. France, however, is a republic with the spirit of an empire. And the economic stress has been less severe in France than elsewhere.

In the process of political evolution democracy is our latest form of government, but this does not mean that it is going to be our last. It is almost wholly a development of the past hundred years and largely a product of the past fifty. Even the most valiant among its early protagonists did not expect democracy to serve permanently as a scheme of rulership. Thomas Jefferson, for example, had no such expectations. Better, perhaps, than any other statesman of his time he saw the limitations as well as the merits of a government dominated by the desires of a great and varied populace. Hence his prediction that as countries became industrialized, with large masses of people concentrated in the cities, the strain that would be put upon popular government might prove heavier than it could bear.

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[1] Address of the retiring vice-president and chairman of Section L—Historical and Philological Sciences, American Association for the Advancement of Science, New Orleans, December 31, 1931.

Jefferson was right in his interpretation of political history. He appreciated the fact that the form of government must be related to the conditions under which the people live, and that such conditions may undergo great changes in the course of a century. Accordingly, he warned his countrymen that they must stand prepared to reconstruct their political institutions from age to age, lest government lose touch with the aspirations of the people whose welfare it was designed to serve. Jefferson was a believer in the democratic form of government because he believed that it best served the requirements of his own day, a day of simple life in a land where virtually the whole people were wringing their livelihood from the soil, where industries were few and small, where there were no large cities and where for the first time in human history a measurable approach to economic equality had been achieved.

But it was not his conviction that a scheme of government based on the principle of mass control would prove effective in all ages and under all conditions. On the contrary, the writings of the great Virginian persistently urged that future generations should periodically reexamine the old dogmas and abandon those which time and circumstance had thrown out of consonance with the facts of national life. Serious harm has been done by the public imagination to various tenets of Jeffersonian philosophy by giving them a universal and eternal application, when they were intended to be of local and momentary relevance only. "This world," said Jefferson in one of his most significant but least-remembered aphorisms, "should always belong to the living generation and not to generations that are past and gone."

New popular governments replaced autocracy during the era between the French Revolution and the Treaty of Versailles, but autocracy did not weaken and fall because it was inherently unsound as a plan of government. During the long feudal régime it was the best and indeed the only effective form of rulership that could have been devised. For centuries the principal function of government was to defend and protect. National defense and the maintenance of order within the realm absorbed almost the sum total of governmental energies. Monarchs and territorial magnates ruled the land because they were the only ones able to muster the national strength in the oft-recurring emergencies.

Gradually, however, the protective work of government became relatively less important as the positive functions developed. Likewise the need for more revenue became imperative; the area of taxation widened; and the people who paid these taxes began to clamor for a share in the control of public policy. Government by the taxpayer thus replaced government by the divine right of kings. But government by the landowners and taxpayers did not mean democratic government in the present-day sense. It excluded from the suffrage a large proportion of the adult population. The doctrine that all men are entitled to a share in the control of their government, irrespective of their property or taxpaying status—that doctrine is the child of the great revolution which swept France near the close of the eighteenth century and presently sent its echoes throughout the whole western world.

Democracy in its present-day sense came in with the declaration of the rights of man and the vogue of an equalitarian philosophy. Based on the postulate of human equality it requires for its successful operation an environment in which a fair approach to social and economic equality is realized. It also demands for its efficient functioning a condition of affairs in which the problems of public policy are sufficiently simple to be within the compass of the average mind. Both these requirements were fulfilled to a reasonable degree, in the United States and in Europe, during the larger part of the nineteenth century. The great issues of that century were mainly political, and such economic issues as arose were not complicated beyond the capacity of the average human understanding.

To-day all this has changed. Economics and politics have become hopelessly intertwined. There is almost no political issue nowadays that does not have great economic implications, and there is no economic issue that does not find itself enmeshed in the complications of politics. People do not realize how enormously the functions of government have expanded during the past fifty years, and especially during the last quarter of a century. To-day the hand of government reaches into every nook and corner of the world's economic activity. By the erection of tariff barriers it dislocates the ordinary channels of international trade. By systems of taxation it can promote or throttle the industrial capacity of the people. By its control of banking and currency and credit it has power to raise or lower the general level of prices. By its network of regulatory laws and ordinances every great government likewise controls transportation and communication, sometimes in a measure which virtually amounts to public ownership. And the vast spread of social insurance, especially insurance against unemployment, has brought in its train a series of economic problems which the governments of European countries seem utterly unable to solve.

The day of rugged individualism and laissez-faire, in a word, is gone and probably gone forever. Democracy came in with the philosophy of hands-off; it linked itself with the proposition that a government is best when it governs least. To-day this proposition has given way to the doctrine that there is nothing which a government should not do if it can do the work better than it would otherwise be done. One would have no fault to find with that doctrine if governments were permitted to use expert judgment in dealing with the problems which come before them. But that is just what governments, democratically constituted, are not permitted to do. They must be guided by popular desire, whether it be judicious or not, for democracy rests on the principle, enunciated by Rousseau, that majorities are always right, even though by every pragmatic test they are proved to be wrong. The submission of complicated economic issues to great masses of semi-illiterate voters is merely referring the decision to the supreme court of ignorance. One may be pardoned for raising, in all seriousness, the query whether a world of steadily-increasing complexity in its human relations can be expected permanently to let its destinies be guided in that way.

Consider the troubles of mankind at the present hour. In larger measure than we realize they are the outcome of political ineptitude. The post-war treaties were framed, for the most part, on the formula of self-determination. Boundaries were redrawn to synchronize with racial groupings. Little or no attention was paid to the economic dislocations which this remapping of Europe was bound to involve. The treaty-makers, for example, set up a new Austria without giving it the economic resources with which to maintain itself. Thereby they forced the Austrian government to seek a customs union with Germany and thus placed an almost insuperable blockade in the way of amicable Franco-German relations.

The new boundaries, as was natural, inspired an orgy of tariff-making which threw trade out of its older channels, cut off the markets for established industries, and forced new home industries into being. These infant industries, sheltered behind tariff walls, became heavy borrowers of capital and contracted obligations which their earning power does not enable them to liquidate. Thus was forged the chain of errors—new boundaries, new tariffs, new industries, new obligations and new bankruptcies.

Likewise the new democratic constitutions which were adopted by European countries at the close of the war had something to do with the accentuation of economic difficulties. Germany, Austria, Hungary, Poland, Czecho-Slovakia, Jugoslavia—one and all they hastened to equip themselves with the accoutrements of up-to-date democratic rulership, including universal suffrage, proportional representation, ministerial responsibility, initiative and referendum, bills of rights and local autonomy. Provision for proportional voting in these new constitutions was a particularly flagrant mistake. It meant the encouragement of party disintegration with government by blocs and consequent executive instability. Conditions in all European countries during the past ten years have called for stabilized, assertive leadership and for parliamentary support of the executive authorities. The new constitutions have virtually precluded either of these things.

The new democracy, moreover, brought with it a new social orientation. Political power passed quickly into the hands of those who wanted all manner of governmental paternalism for their own benefit. Under this political pressure the governments embarked on extensive programs of social amelioration, the costs of which were far beyond their means. Not being able to raise taxes proportionately, the budgets disclosed heavy deficits which had to be liquidated in ways that impaired the national credit and weakened public confidence in the banks. Even in England a feeling of financial insecurity spread widely because of the steady excess of expenditures over revenue—an excess due largely to the gigantic weekly outpouring of allowances to the unemployed which in turn was dictated by the political power of the universal suffrage voter.

This feeling of financial insecurity gave rise to the hoarding of gold and the flight of capital. Bank reserves were depleted at a rapid rate and foreign deposits were withdrawn from the banks in Austria, Germany and England. In Austria the country's largest banking institution closed its doors; Germany called for a moratorium; England went off the gold standard. The chain of events leading to these serious economic mishaps is rather tangled; but in the last analysis the primary cause is to be found in the orgy of unsound governmental financing, with wasteful public expenditures, badly unbalanced budgets, steadily recurring deficits and the imminent prospect of inflation as the only way out—all of which must be laid at the door of the New Democracy.

The United States has fared better than most of the European countries and chiefly because we have indulged in no such carnival of governmental extravagance. Our troubles are due in larger degree to the excesses of private enterprise. But there is no certain assurance that, during the next year or two, we may not be led by popular clamor into a repetition of Europe's financial folly. Already there is a widespread demand that the national government shall proceed to restore prosperity by squandering the people's money on a large scale. No nation has ever achieved a restoration of prosperity in that way. The argument is, however, that no nation ever faced an economic crisis of such severity as that which the United States is now passing through.

Such an argument is not based upon the facts of history. The economic situation in the United States is bad enough at the present time, and it may grow worse; but it has not yet reached the point where it can be termed relatively more serious than any such occurrence in the past. A little less than a hundred years ago, for example, we had a major depression in the United States with many features similar to the present one. The era from 1829 to 1837 was marked by an orgy of speculation which had no parallel in the previous history of the country. The building of the Erie Canal and the Cumberland Road, together with the construction of many internal improvements, led to widespread speculation in land. New territories were opened up to more convenient communication, and people discounted the value of these lands far into the future. The speculation backwashed into the cities along the Atlantic seaboard and real estate values were inflated beyond all reason. The rise in land values was accompanied by a general rise in the level of commodity prices, particularly in the case of agricultural staples such as grain and cotton. This rise extended to manufactured products also, and imports from Europe were greatly increased during the period. Everybody went speculating. As most of the population were engaged in agriculture they naturally speculated in land.

This great inflation of values naturally affected the banks, which were called upon to provide the funds for purchases of land and commodities at the enhanced prices. The total circulation of all the banks in the United States was about forty-eight million dollars in 1829. Eight years later this had more than trebled and amounted to one hundred and fifty million dollars. Bank loans went a similar expansion. They totaled about one hundred and thirty-seven million in 1829 but rose to well over a half billion in 1837.

The panic of 1837 came quickly and was of great severity. Land values came tumbling down within a few weeks. The decline in values was in some cases as much as 80 per cent. The result was that banks all over the country found themselves solidly frozen and almost all of them had to close their doors. Just substitute common stocks for land and you have the collapse of paper-wealth in 1837 repeated in 1932. The similarity in some features is impressive. For example, after the first crop of bank failures there was much hoarding of currency. There was a very large deficit in the financial operations of the national government. In 1838 this deficit amounted to twelve million dollars, which was the largest ever encountered in time of peace down to that date.

In some respects the crisis of 1873 bears an even closer analogy to that which we are now experiencing. There was a primary recession immediately after the close of the Civil War, just as we had a similar phenomenon in 1921–22 almost immediately after the close of the World War. This primary setback was of short duration in both cases. In 1867 it was followed for a six-year period by an epoch of unprecedented expansion in American industry and transportation. This was the heyday of railroad building. Over thirty thousand miles of new railroads were built during the six years between 1867 and 1873, the construction of these roads being stimulated by land grants and bonuses from states and municipalities.

This orgy of construction was financed by the issue of bonds and stocks in hitherto unheard-of amounts. A substantial proportion of these securities was sold abroad, more particularly in England, but much was absorbed by banks, by other financial institutions and by individuals in the United States. Soon these securities rose to values which were wholly out of line with the earnings which the railroads could possibly expect to make in any man's lifetime. The building of the railroads naturally stimulated various allied industries, such as iron mining and timber, so that the facilities for production in these industries were enlarged beyond all normal needs. Likewise the new transportation lines made agriculture more profitable because it enabled the farmer to market his products more readily, and this increased profitableness quickly led to the overproduction of grain. All in all, everything was made ready in 1872 for a general collapse.

The panic of 1873 was more than a panic. It was the beginning of a rather prolonged period in which all values kept slipping downward. Security prices took the first plunge, followed closely by real estate values. Wholesale prices quickly joined the retreat; then retail prices had their inning, and wages went down last of all. In fact retail prices and wages were still going down when securities, land values and even wholesale prices had begun to move up again.

The first indications of a turn during a depression make themselves apparent in a hardening of certain wholesale prices. The rise begins with consumer's goods, that is, with staple commodities like wheat, corn and cotton which are rapidly used up. This is followed by a stabilizing of wholesale prices in commodities of greater longevity, such as steel, copper, rubber, lumber and leather. Meanwhile, security prices respond to the earliest of these omens; hence it usually happens that securities start upwards and proceed a considerable distance, while the income from these same securities is still going down. This is quite likely to be the case during the next few years. Investors must not expect to see their dividends put back to the old figures for some time; on the other hand, the capital value of their investments may double or even treble within a relatively short period. This is because security values reflect the prospects of earnings rather than the actualities. Accordingly we must look for a reduced yield from the federal income tax, even though the rates be considerably increased.

Our most immediate danger in the United States is that we may repeat, at the present juncture, the folly of European countries by failing to cut governmental expenses, by borrowing to cover deficits and by using the public credit wastefully. Already there is being put upon Congress and the state legislatures strong pressure to embark on such a course. The national finances for 1931–32 will show a formidable deficit, perhaps the largest that the United States has ever had in a year of peace. For 1932–33 the budget of the United States can only be balanced by a drastic cutting of public expenditures as well as by far-reaching increases in taxation. Will the American democracy show the good sense and courage to adopt these measures, or will it be drawn into the vortex of unsound public financing as European democracies have been?

Meanwhile the events of the past ten years ought to convince the world that economic laws and forces are just as inexorable as the laws of nature. One of these is the proposition that extremes generate their opposites. Where there are peaks there must be valleys. That is just as true in economics as in geography. Nevertheless each successive generation of men insists on producing an era of artificial prosperity followed by an interlude of violent reaction. So whether our present troubles clear up quickly or endure for several years there is one prediction which can be made with absolute certainty, *viz.*, that after the American people have evolved from their present cycle they will proceed to run the same course all over again.

Our great-grandfathers delivered the panic of 1837; our grandfathers went them one better in 1873; our fathers repeated the trick in 1893; and we have managed, somewhat tardily, to follow their example with our present-day mess. Unless all history has been written falsely and all psychology is unsound, our children will achieve a first-class financial depression somewhere in the fifties, and our grandchildren will see that still another one is forthcoming before the twentieth century reaches its close. It is an amazing thing that man's control over nature has become so nearly complete during the past hundred years, and yet his control over relations with his fellow-men, particularly his economic relations, has not been conspicuously improved.

In Europe the general impatience with democratic institutions is more pronounced to-day than it has been at any previous time within human memory. Hence, if democracy is to be saved, the United States will have to do it, and the next couple of years will show whether we are equal to the task. The rescue will not be accomplished by cancelling Europe's indebtedness or by lending new funds to the Old Continent, but rather by putting our own house in order—by trimming public expenditures, by increasing public revenues in ways which will not unduly increase the burden on industry, by refusing to be drawn into extravagant schemes of social welfare which in the end react to the disadvantage of those whom they are designed to help, and by restoring public confidence in the country's institutions of credit. In a word, democracy can be preserved by demonstrating that at least one democratic country can keep its head.

THE SOCIAL SIGNIFICANCE OF AMERICAN PANICS[1]

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A PROMINENT American banker, whose name is found frequently in the public press, has recently remarked that the experience through which America has been passing since the severe financial panic in October, 1929, is both unprecedented and unusual. Unfortunately, of course, depressions, panics and wars have alike punctuated human history, and our present experience, far from being either unprecedented or unusual, has in all its fundamental features been matched by that of every generation of Americans. Indeed, it is tempting to go, with Ferrero, much further back to a civilization so curiously like our own and to the great depression in the third century of the Christian era, which in the judgment of at least one brilliant historian paved the way for the fall of the Roman empire. The student of economic similarities might even find materials in the Egypt of the Pharaohs and in the seven fat years and the seven lean years of the book of Genesis. But though we read of long depressions with momentous social consequences among the Chinese, the Babylonians, the Assyrians, the Greeks, the Romans and the people of medieval Europe, only one business cycle in all recorded history seems to have had a Joseph, wise or lucky, and able to prepare in the fat years for the lean years which lay ahead.

One common feature of all these early depressions is their length, perhaps because those that lasted a mere seven years seem across the vista of the years too brief to be worth remembering. Among other periods of fifty or a hundred years, there have been historians to suggest that even the two hundred years of the crusades are to be explained in part by the practical necessities of a very long economic depression. Face to face with over-production and unemployment in the most lucrative trade of the age, the knights and soldiers who took service under the banner of the cross may have been actuated by motives not unlike those that in a later age brought the dole to England and the community chest and other temporary forms of relief to the hard-pressed America of our own day. Each time, too, in other centuries, as men have passed through periods of depression, they seem, at least sometimes, to have learned the lessons that adversity enforces, and have at length, soon or late, escaped by new methods of government, by the adoption of new business institutions better suited to the times in which they lived. From their own point of view, each generation seems thus to have found at last an opportunity to rise on stepping stones of its dead self to higher things.

But be these more remote examples as they may, one needs to go no further back than the beginnings of the seventeenth century and to the founding of America for the certain records of a people whose history has been marked in each generation and at every crisis by a very serious and sometimes long-continued depression. At the very threshold we find more than a little evidence that the fundamental and persistent cause of that astonishing movement of population that Woodrow Wilson called the swarming of the English was the hard necessity of poverty. The enclosure of the fields of the English peasant and the decay of the ancient guilds were of course not new, but their full effects were only visible in the closing days of Elizabeth and in the reign of her successor. Even in the early sixteenth century Sr. Thomas More had written burning words regarding the difficulties of the unemployed. More than once he had seen husbandmen compelled to sell their little homes and "depart away, poor innocent wretches, goods, men, women, husbands, wives, fatherless children, widowes, woeful mothers and their young babes . . . out of their known and accustomed houses, finding no place to rest in. And when they have wandered abroad . . . what can they else do but steal . . . or go about begging? And then also they be cast in prison as vagabonds, because they go about and work not, whom no man will set to work." How often in later days, would the same description prove to apply!

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[1] An address given at the eighty-ninth meeting of the American Association for the Advancement of Science on December 31, 1931.

Fifty years later conditions were worse, rather than better. Many thoughtful Englishmen now pointed out the possibility of finding a solution for prevalent unemployment by a consciously directed policy of colonial expansion. Thus Sir Humphrey Gilbert, who was to give his life to the enterprise that he advocated, wrote in 1574: "We might inhabit some part of these Countreyes (America) and settle there these needy people of our country which now trouble the Commonwealth and through want here at home are enforced to commit outrageous offences whereby they are daily consummed with the gallows." In 1611, four years after the first settlement of Virginia, the watchful Spanish ambassador, Velasco, wrote to his master: "Their principal reason for colonizing these parts is to give an outlet to so many idle wretched people as they have in England, and thus prevent the dangers that might be feared of them." It is noteworthy that the decade of most severe depression came from 1620 to 1630, a time in which the foundations were laid for more than one future American state.

The earliest of purely American panics came to the various colonies, especially the tobacco regions of Virginia and Maryland, during the reign of Charles the Second. The number of people living in America was, of course, a mere handful, but the sequence of events was strikingly similar to that of a later age in the complicated industrial and banking community. A period of great prosperity, in which the price of tobacco had been high, trade active and the plantation system constantly fed by new importations of indentured servants, was succeeded by very hard times in which tobacco became a mere drug on the market. As usual, these difficulties pressed with great force on the recently established western farmers, some of whom had been indentured servants on the larger plantations of the wealthy men of the tidewater region. The results, as every one knows, were highly dramatic; for the western men in deep distress blamed their chief difficulties on the selfish policy of the aristocratic governor, Sir William Berkeley, and the group of favorites that surrounded him. By a curious coincidence in dates, just one hundred years before the declaration of American independence, which had in some respects a similar social as well as a political significance, the common people found a leader in a young planter named Nathaniel Bacon, a relative of the renowned Lord Chancellor of England. With the assistance of two friends, the Scotchman, William Drummond and "the thoughtful Mr. Lawrence," as he was called by his neighbors, and under the pretense of defending the colony against the Indians, Bacon raised the standard of revolt, gained some initial successes, compelled the governor to accept far-reaching democratic changes in the government of the colony, and proved his power by capturing the seat of government at Jamestown and burning the houses of that center of conservative control. But Bacon and his friends were ahead of their day, and the death of their leader left the discontented rabble unable to cope with the prestige of the wealthy planters under the banner of legitimate authority. A movement of great significance, which had had reverberations in places as distant as North Carolina and Maryland, suddenly collapsed. Bacon was dead, the dour Drummond was soon captured to meet the fate of traitors, and the thoughtful Richard Lawrence barely escaped into the wilderness where perhaps under some new name he was able to take up again the career that he had left behind.

The results of this episode were probably more permanent and significant than the hard fate of the leaders would lead one to suppose; but when the early chroniclers looked for the causes of a great depression and of the revolt which came from it, in typical seventeenth century fashion they selected features in the general situation which were unique rather than those that suggested a common experience in the history of such revolts. Thus a sober and detailed story of these events, the one to which historians have been chiefly indebted, commences at once and boldly by a type of explanation as much in fashion in those distant times as the theories of the business cycle are to-day:

> About the year 1675 [writes the planter whose initials are appended to this document] Appear's three Prodigies in that country, from which th' attending Disasters, were looked upon as Ominous Presages. The one was a large Comet every evening for a week or more, at Southwest; thirty five degrees high, streaming like a horse taile westwards, until it reached almost the horizon, and setting towards the northwest. Another was flights of pigeons, in breadth nigh a quarter of the mid-hemisphere, and of their length was no visible length; whose weights brake down the limbs of large trees whereon these rested at nights, of which the Fowlers shot abundance and Eat 'em. This sight put the old planters under the more portentous apprehensions, because the like was seen (as they said) in the year 1640 when the Indians committed the last massacre, but not after, untill that present year 1675. The third strange appearance was swarms of Flyes about an inch long, and big as the top of a man's little finger, rising out of spigot holes in the earth, which eat the new sprouted leaves from the tops of the trees without other harm, and in a month left us.

And after this remarkable introduction, the truthful Thomas Mathew, for such was probably the author's name, continued with evident impartiality to recount the events of the next two years in the old colony of Virginia.

For the purposes of this brief review, passing over other depressions of the colonial period, of which the one in 1764 was the most notable, America had barely escaped from the political and military dangers of the period of the Revolution when she was face to face with the first of the panics of the national period. As is now well known, the hardships of the war had been largely limited to the tattered soldiers of Washington and Greene and to those communities which had been the scene of bitter civil contests between the patriots and the loyalists. In other places, money had never been so abundant, for both the British and the French had war chests and distributed gold and silver, in the colonial period almost unknown, with what seemed at the time prolific hands. Especially in the neighborhood of the seaports where the foreign soldiers were established the farmers found a ready market for their crops and even the artisans were working hopefully under the influence of high wages. The inflation of the monetary medium, due to the large issues of Continental bills and of local forms of paper money, increased prices as if by magic, and made it comparatively easy for the debtor to meet his obligations. Such prosperity in many places helps in part to account for the patience with which the American people endured the disadvantages of so long and so uncertain a contest. In New England, it is true, the old trade routes to the West Indies were no longer safe, the fisheries on which so many had depended for a livelihood were closed, and the whaling ships remained for years at their wharves in Nantucket. But war brought new opportunities and enterprising shipmasters laid the foundations of new fortunes by engaging in the adventures of privateering. The fictitious prosperity of the war years led to speculations in lands and to the investment of profits in shops for the manufacture of commodities that had once been furnished by the mother country.

When the war was over, conditions changed so quickly that many persons who had counted on the continuance of good times found themselves in sudden difficulties. The prohibitions of the European mercantile systems were now made general and permanent. Imports destroyed the prosperity of more than one little factory. Gold and silver left the country in payment for luxuries, and prices generally dropped with alarming rapidity. The conditions which had existed in Virginia one hundred years before on a small scale were now repeated on a continental scale. What seemed the harsh exactions of the creditors produced demands for paper money and other means for the relief of debtors, precisely parallel to the remedies that were later to be lumped together under the name of populism. From the point of view of the conservative classes, whose leaders were bound together by a consciousness of kind, the dangers of the times were merely emphasized by Shay's rebellion of 1786, put down in the dead of winter at the private expense of the great merchants of Boston. And there can be little doubt that the meeting of the constitutional convention which established a strong government capable of dealing with the dangerous excesses of democracy was hastened and made possible by the fears which the events of the great depression had made so clear. New trade routes were now opened across the Pacific to Asia, and the dangerous and discontented were drained away to the opening West, where they were to modify their institutions and to inaugurate the middle period in American history.

Before the next depression, the generation that remembered the troubles of 1786 had passed away. An era of speculation followed the close of the Napoleonic wars. In America this took the form of a great land boom. Great areas were bought on credit, and pretentious towns were laid out in regions that were to remain for many years thinly inhabited. Then came the crash. Staple productions fell to less than half their former price; land values declined 50 to 70 per cent.; manufacturers were in distress; laborers were out of work, merchants were ruined. In Cincinnati, whose condition was typical, by the foreclosure of mortgages, the national bank came to own a large part of the city—hotels, coffee-houses, warehouses, stables, iron-foundries, residences and vacant lots. Throughout the West and South, the bank became known familiarly as "the Monster." Out of the panic of 1819 came consequences no less momentous than those of thirty years before. Among these were the rise of political consciousness on the part of men who had previously been quite willing to let their betters do their thinking for them, growing demands for a more liberal suffrage, for the abolition of debtors' prisons, and above all for the division of the public lands of the West in smaller units and on more favorable terms. Instead of the minimum of 640 acres that had been proposed by the aristocratic Hamilton, good land could now be bought in farms of only eighty acres and for as little as one dollar and twenty-five cents an acre.

As in the case of the earlier depressions, 1676, 1764, 1786, the most marked consequence was a new movement into the West, in which broken business men and discouraged debtors were in the van. Even the vast reaches of the Middle West, where so much of the land had fallen into the hands of speculators, did not prove to be sufficient to satisfy the longing for escape which had been so common a feature of the great American depressions. Moses Austin, an enterprising Yankee, who had been engaged in the iron business first in Virginia and then in Missouri, found himself hopelessly involved in the meshes of the great panic. Without despairing, he decided to give up his citizenship and gained a grant of land in distant Texas where under the banner of Spain he might carve out for himself a new career. He did not live to carry out his plan, and it was left for his abler and less visionary son to become the founder of a new commonwealth. And not the leaders only. For history again repeated itself, and no one can study the records of the early settlers in Texas without being impressed with the extent to which they came to avoid adversity, just as their forefathers had once served a hard period of indenture in the old days in Virginia.

Our editorial writers who speak of the panic of 1929 as one of unusual severity and significance have surely forgotten 1819 and have certainly overlooked 1837. For in that year the story was much the same, except that this time there was no war, and that speculation had taken the unusually unfortunate form of canal building at a time when every month made it clear that the canal was doomed in competition with the steamboat on the rivers and especially the now rising railroads. Consider the fact that not some of the banks in the United States, but that every one closed its doors to its creditors and refused to meet its obligations in specie, that the burden of hopeless debts was so heavy that a reluctant Congress was compelled to pass a general bankruptcy law by which thousands of distressed debtors were relieved from their obligations, that six states behind the bulwarks of the eleventh amendment were so involved that they repudiated their public debts either in whole or in part, and that of these debts eleven millions have never been made good until this day, and we have a few hints of the seemingly measureless calamity that had overtaken a nation that only one year before had been riding high on the crest of a wave of rising prosperity.

Against the sufferings of 1837 our recent experiences seem minor and insignificant. Captain Marryat, the English novelist, reached New York in the midst of the panic and has left a vivid description of his experiences:

> Two hundred and fifty houses have already failed, and no one knows where it is to end. Suspicion, fear and misfortune have taken possession of the city. Had I not been aware of the cause, I should have imagined that the plague was raging. . . . Not a smile on one countenance among the crowd who pass and repass; hurried steps, careworn faces, rapid exchanges of salutation, or hasty communication of anticipated ruin before the sun goes down. Here two or three are gathered together on one side, whispering or watching that they are not overheard; there a solitary, with his arms folded and his hat slouched, brooding over departed affluence. Mechanics thrown out of employment, are pacing up and down with the air of famished wolves. The violent shock has been communicated, like that of electricity, through the country to a distance of hundreds of miles. Canals, railroads and all public works have been discontinued, and the Irish emigrant leans against his shanty, with his spade in his hand, and starves as his thoughts wander back to his own Emerald Isle.

For the first time in the panic of 1837, we begin to have definite statistical proof of the severity of the sufferings of the individual as marked by the figures both for suicide and by the number of convictions for crimes. With abundant resources, in an empty continent, America was passing through an experience like that of seemingly overcrowded England in the days when Sir Thomas More wrote his "Utopia," and the social incidents differ only in the details of the time and the place.

Pass on twenty years, this time, through a period of great prosperity, in which America becomes the granary of the world and the haven of the starving and the distressed. If the panic of 1819 may be called our great land panic, and that of 1837 the canal panic *par excellence,* that of 1857 was surely the first of our two great railroad panics. Consider an editorial from *Harper's Weekly* for October 10, 1857, which sounds as if it were written yesterday:

> It is a gloomy moment in history. Not for many years—not in the life time of most men who read this paper—has there been so much grave and deep apprehension; never has the future seemed so incalculable as at this time. In our country there is universal commercial prostration and panic, and thousands of our poorest citizens are turned out against the approaching winter without employment and without the prospect of it.
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> In France the political cauldron seethes and bubbles with uncertainty; Russia hangs, as usual, like a cloud, dark and silent, upon the horizon of Europe; while all the energies, resources and influence of the British empire are sorely tried, and are yet to be tried more sorely, in coping with the vast and deadly Indian insurrection, and with its disturbed relations in China. Of our own troubles no man can see the end. They are fortunately, as yet mainly commercial; and if we are only to lose money, and by painful poverty to be taught wisdom—the wisdom of honor, of faith, of sympathy and charity—no man need seriously to despair. And yet the very haste to be rich, which is the occasion of this widespread calamity, has also tended to destroy the moral forces with which we are to resist and subdue the calamity.

Wise words, which, if they could be remembered by more than a single generation of men, might go far to prevent the next catastrophe!

But the very next experience of the kind came in a shorter period than had been usual, and was probably hastened by an increase of the spirit of extravagance and corruption which seems to be the inevitable consequence of every long war.

Of all our panics, this one which lies like a storm cloud across the years after 1873 has most points of likeness to our most recent depression. It came just eight and a half years after the conclusion of our most costly war; it began in Germany, which had a panic at almost the same moment as the United States, and from central Europe spread to France and Belgium and thence to England and all parts of the world. Everywhere currency inflation, with rising prices, wages and speculation, made itself conspicuous, and provoked a sharp reaction. Some panics have come out of a clear sky with unexpected suddenness, but in the America of the seventies cautious observers had expressed a fear that the currency was too much inflated, that the railways were being overbuilt, that there was overtrading, and habits of luxury and extravagance were apparent in the expenditures of individuals and in the rising budgets of cities and corporations. In the spring of 1873 the money market was so badly shaken that some of the close friends of the eminent financial wizard, Jay Cooke, begged him not to carry forward a syndicate to build yet another unneeded railroad across the plains. Throughout the first half of the year, the revelations in the Credit Mobilier scandals proved to the most unwary the manifold waste that was involved in the use of public funds for private enterprises, and scandals in the field of railroad promotion were matched in the business of banking and insurance.

The crash came in September, the most dramatic incident being the failure of Jay Cooke and Company, which had been regarded as a very pillar of financial stability. The public was still incredulous, and a newsboy, shouting, "Extra, all about the failure of Jay Cooke," was arrested by a horrified policeman, who still felt it was the duty of the patriotic to whistle against the rising storm.

The panic, like all others, spread in widening circles and involved many who had no part in the era of corruption and speculation that had preceded. The building of railroads was suspended for lack of funds, giving an adventitious importance to unexpected terminals which soon became the rendezvous of the cattle drivers and gained the temporary eminence of the cow towns. Rolling mills, machine shops, foundries and other industries connected with rail transportation were closed for lack of orders, and as the winter approached laborers to the number of hundreds of thousands were thrown out of work. In the cold weather of 1874–5, long bread lines and demands for outdoor and indoor relief were common features of the life in great cities. Despite an abundant harvest, cases of actual starvation were not uncommon. Two years later, conditions had failed to improve, and the newspapers were devoting editorials to the "tramp-evil." From all over the East came reports of thefts, incendiary fires, rapes and even murders committed by vagrants. In some New England towns people on the outskirts were compelled to abandon their homes and in Massachusetts alone there were said to be a thousand vagabonds roaming the rural communities. Two hundred desperate tramps invaded a village in central Illlinois, and were only repulsed after a bloody encounter with the marshal and his constables. No one at the time regarded it as a function of government to bring any remedies to bear on a desperate situation. One statesman, James A. Garfield, said that it was no part of the business of government to find jobs for the unemployed. And this sentiment was widely applauded. In these circumstances, the American people found their own remedy in enforced economy. In the first year after the beginning of the panic the consumption of silks and other luxuries was decreased by more than four hundred millions. But even economy was no panacea, and the skies remained dark until the summer of 1878, almost five years after the commencement of the panic, when crop failures in other parts of the world created a new demand for American products, factories began to open, and life to return again to its normal channels.

The end of the reconstruction experiment in the South, the rise of agrarian power and discontent in the West, the introduction of windmills and barbed wire into the plains of the great West, the temporary supremacy of the cow towns at the end of unfinished railroads were unforeseen contributions of a great panic to the social history of the nation.

The story of our three last panics is too familiar to need recounting. In one respect they belong to a different cycle. For the cities rather than the West have become the true American frontier, and the movements of population which always follow a panic take a different direction. But the incidents again sound strangely similar, and in each case, in 1893, in 1907, and now in 1929, it is apparent that the nation has again stood at the crossroads of social and political change. We are somewhat too close to these events to be able to estimate their significance. But a few consequences are almost too obvious to require comment. Thus out of the tribulations and uncertainties of the nineties came the relative stability of the gold standard as established in the act of 1900. Similarly, the reform of the banking system in the Federal Reserve Act of 1913 can be traced directly to lessons learned in the panic of 1907. However gravely we may differ in our theory of the causes of panics, their social consequences have been both similar and momentous. Indeed, from the point of view of morals and of institutions, the periods of prosperity often appear in perspective relatively static and hopeless; and with all the sufferings which are incident to periods of depression, it is from these events that we are able to trace the process by which injustice has been lessened, ideals aroused and progress made possible.

Thus from the first tobacco planter in Virginia to the industrial and financial leaders of our own day, even when we leave out of account the minor rise and fall of the business cycle, no man has been active in the industrial or business life of his own time for as much as thirty years, without having the opportunity of at least one period of great and unusual prosperity and similarly passing through the gloom and the darkness of one depression. Curiously enough, if you consider spacing of these depressions, they seem to fall sufficiently far apart to make it unlikely that any single business man in the period of an active life of average length will ever be lucky enough to pass through more than one of these unusual periods of prosperity or unfortunate enough to have to meet more than once the oft-repeated problems of more than a single general depression. Accordingly, the individual who gets through with his panic early seems to be in a singularly fortunate position, and can hope with some slight confidence that the next major depression will fall in the life of his successor. On the other hand, the person who meets the crushing force of a depression in the later years of middle life, has more than once found the remaining years all too short to overcome the sudden disadvantages which have been imposed.

In all the abundant literature which has arisen from these depressions no one seems to have suggested the most obvious explanation that something may be due to the capacity of each generation of men to learn something from their own experiences and to guard against mistakes which events have made all too clear. From the superficial view of the historian, at least, there is more than one indication that men have often understood at the time, just as clearly as we can point out to-day, the fundamental causes of their own misfortunes, and that the generation of planters or bankers or stock brokers which has just passed through one of these oft-repeated human experiences is apt for a time to be fortified against similar dangers. So the persons who have lived through one great war are surely likely to handle the dynamite of international animosities with peculiar caution. But time is long and memory brief, and neither the diplomat nor the business man is skilful in using history, the long memory of the human race, as an aid to the recognition of old dangers under strange new forms, and so, in answer to the insistent demands of human greed or human ambition, twenty or at the most thirty years suffice to wipe out all effective memories, to clothe the hideous details of the last war in the attractive illusions of a glorious adventure and to make of the thoughtless cult of prosperity something of a passionate dogma against which even the boldest may not stand with impunity. In the meantime, often, the institutions in business or in government, which were designed to prevent the recurrence of similar evils in the future, have sometimes reached maturity and have begun to decay without prompt recognition of changed circumstances. Similar forgetfulness and institutional decay may, perhaps, in a larger philosophical view, help to account for the curious rhythm in these phenomena. If so, it may not seem strange that each generation has had to face its major war and likewise its major panic, and that the length of time between two of these occurrences is roughly similar.

The earlier theories of panics by European writers, beginning with Sismondi in 1818, and varying from the determinism of Jevons with his sun spots to the half-humorous individualism of Walter Bagehot, who suggested seventy years ago that panics might be prevented if only the Lord Chancellor could control the investments of rectors, grandmothers and other foolish people, have of course had their echoes in America. But the favorite explanations have always laid the chief blame on the relative scarcity or abundance of the monetary medium. Unfortunately, such theories do not seem to be especially helpful at the time, for while one group of contemporary writers blame all the evils of the period to a currency that is too abundant, others are quite certain that it is too scarce. In 1786, in 1819, in 1873 and in 1893, the remedies suggested for depression were as far apart as the two opposite financial theories of the cause. And while uncertainties as to the value of money have been a common feature of panics and depressions, they have been by no means universal, suggesting the possibility at least that the supposed cause is after all a symptom and that the real origins of these phenomena, even though they do not lie quite so deep as the meteorological theory would suggest, are somewhat more complex than the mere quality of the monetary medium would lead one to suppose. Certainly at the beginning of the present depression there was little uncertainty as to the stability of the gold standard and the level of prices did not show that marked inflation which would account for the length or the severity of the depression. It is accordingly unlikely that similar experiences can be avoided, though they may be mitigated, by regulating the mere quantity and value of the general monetary medium. The passage of the gold act of 1900 was hailed by a paean of praise in the great New York dailies, and one went so far as to describe the act as one that was destined to end panics in America. Similarly, the experiences in the brief depression of 1907 were undoubtedly a motive of great force in producing important and far-reaching changes in the institution of banking culminating in the Federal Reserve Act of seven years later; and though the newspapers with even greater unanimity proclaimed the act to end panics, just as later the same journals saw the possibilities of a war to end war, we have now lived to the time when one great nation has avoided a depression by accepting a permanently depreciated currency, all the theories of stability to the contrary, and another in the very sink of bitter calamity has been compelled to abandon the gold standard at least for the time as the only possible escape from a hopeless financial dilemma. And the United States with abundant gold and a well-regulated system of national banking has escaped only in part the dangers of an almost universal situation. The explanation lies evidently somewhere else.

But in mentioning without seeking to analyze well-known general explanations of all panics, I had almost overlooked the astonishing similarities between the current explanations of the two chief groups of politicians at the time of each recurrent depression. One group, the one in power at the time, emphasizes always and in almost the same words, the universal and inescapable character of a depression against which no human wisdom could possibly have guarded, but from which with faith, courage, and especially by continuing to vote the right ticket the country may yet be delivered. Turn to the literature of 1837, 1857, 1893 and all the rest, and, if history does not repeat itself, the words of politicians often do; and you will at least discover the unconscious sources of the political addresses of next year. The views of the opposite group of political leaders suggest that while general causes had no minor part in the calamities which are so well known, the chief blame lies in the cowardice, the weakness and the folly of the party in power. The truth as so often may perhaps be discovered half way between; for while there have been no cases of real world panics, and even in the worst some important countries have either by wisdom or good luck managed to escape, and while most panics, including the last, have in each country been made more terrible by the ineptness of statesmanship, no one in his senses, after the heat of passion has died down, would be apt to place the most obnoxious politician in any leading rôle. But while these contemporary theories, one impersonal and fatalistic, the other individualistic and personal in a highly concrete way, may have no scientific value, the historian can not overlook the fact that men have believed sincerely in the Jackson panic, the Buchanan panic, the Cleveland panic, the Roosevelt panic, the Wilson panic, and that even in these days of scientific enlightment, of which the meeting of this association is so eloquent a proof, if the phrase, the Hoover panic, is not yet familiar, it will undoubtedly come to life next year. The fatalism and the individualism of the politicians, while actuated by more obvious and immediate motives, carries the two groups no further apart than the fatalism and the individualism of the economists, and leaves the average layman, of whom the historian is necessarily an ignorant and eloquent example, stranded in a medley of alluring but unconvincing explanations.

The fatalistic view of panics, whether in its political or its economic phase, and it has both, is sometimes given special precision by the comparative nearness of some great war, and politicians and business men alike, whose deeds are in grave danger of being subjected to the pitiless analysis of the theory of individual responsibility, seize at once on so convenient and so hateful a scapegoat. And with much truth; for most men feel that in some half-realized way the waste, the extravagance, the moral decay which accompany a great war are connected with panics and depressions, some of which come many years later. So, even at the time, the panic of 1819 was readily explained, without any sharp effort at causal analysis, as the inevitable aftermath of the Napoleonic wars in which at the end America, of course, had become involved. This view was especially common among the New England Federalists, who had so bitterly opposed entrance into the war. Again in 1873, the explanation lay somewhat ready to hand, in the fierce struggle that had ended eight years before. A few contemporary economists have even attempted to make the connections more sharp and to account for the disturbing fact that in the most notable cases where panics and depressions have been causally connected with wars, the hard times in their most extreme form have ordinarily come so long after the deeds they are supposed to commemorate. From this point of view two panics follow every great war. The first, of which the depression of 1921 is an example, is called the primary depression and introduces a long period in which agriculture and the extractive industries generally, unduly stimulated by the needs of a wartime demand, find themselves face to face with reduced prices for wheat, cotton and other products. The result is an agricultural depression, which proves to be actually beneficial to the city dwellers, and leads to an over-expansion of industry, far beyond the possibilities of the impoverished but consuming farmer. Then comes the major or the secondary panic, some eight years later, in which country and city, agriculture and industry are at length involved in common though unforeseen calamity. A theory of primary and secondary panics, when tested historically, fits with reasonable accuracy the events after the Civil War, where a brief depression in 1866 was followed by a calamitous panic in 1873 and is again emphasized by recent history, where the depression of 1921 and that of 1929 follow at almost the same interval. But after other wars, the formula, in America at least, is no longer good. Thus after the Revolution, there was one great depression and not a pair, and again after the war of 1812, there was a single depression in 1819. But since in both cases America was still predominantly agricultural, these very exceptions may prove the rule. In other words, primary and secondary panics may be necessarily merged where the country has a simple form of economic life, either industrial or agricultural, to the exclusion of the other. All that one can say is that a country balanced between agriculture and industry has at least in America lasted too short a time, to make such a precise theory capable of convincing proof, and the chances are that when the next war comes with its next cycle of panics economic conditions may have changed in so many and such unforeseen ways as to make necessary still another theory of the exact relation of wars to depressions. Nothing can illustrate better the fact that history is history and not economics and that there are limits to the inductive and historical approach to economic theory which no diligence is ever likely to overcome.

It might perhaps be possible to classify American panics as war panics and peace panics. For if we apply the simple logic of the method of agreement and difference, it is at once apparent that if we place 1764, 1786, 1819, 1873 and 1921 in the first category, there are others equally notable which lie in long periods of profound peace. To this group undoubtedly belong the severe depressions of 1837 and 1893. Conversely, if there have been panics without wars, there have been wars without panics. Thus the Mexican war, which for the times was sufficiently costly, was followed by no panic. Similarly, there have been historians to suggest that the buoyant optimism of the period of the Spanish American war, in which soldiers went to Cuba to the tune of "There'll be a hot time in the old town tonight," was at least in part a reaction against and a way of spiritual escape from the gloom and depression of the years which had preceded; but no one has argued that the brief rich men's panic of 1903 or the so-called Roosevelt panic of 1907 were in any sense primary or secondary depressions having any relation whatsoever to the military history of 1898. Indeed all the evidence seems to point to the conclusion that these depressions are to be explained by factors that were peculiar to the business conditions of their own time. Accordingly, no one would maintain that all wars cause panics and that all panics are caused by wars; so that if any general theory be possible, it must arise out of some common condition, frequently present in long periods of war, but which may with almost equal ease manifest itself in periods of profound peace.

Indeed the last illustration suggests another possibility. For if some wars are followed by almost inevitable panics, the reverse is equally true, and American history furnishes more than one illustration of cases where the circumstances of a panic have paved the way for war. Thus 1764 lies at the end of one war and at the origins of another. Most notably, the panic of 1857 fell with crushing force on the rising industries of the North and West and left the South untouched. Indeed, during the years of depression the price of cotton was unusually high and speculation in field hands went on at feverish pace. Accordingly, Northern communities which had usually voted the Democratic ticket became peculiarly susceptible to the arguments for high protective tariffs which Horace Greeley was spreading broadcast through the influential pages of the *Weekly Tribune*. The stage was thus set for Republican victory in 1860. In the meantime, the continued prosperity of the South gave new meaning to the slogan that "Cotton is King" and made more than one planter deaf to the cautious arguments of such men as Alexander H. Stephens and Sam Houston. From this point of view, it is not improbable that the panic of 1857 had quite as much to do with secession and civil war as such dramatic incidents as John Brown's raid which once occupied so exclusively the attention of the historians of the war between the North and the South.

But the most obvious and superficial method of classifying American depressions is by their length. And this method may not be without suggestive possibilities. Thus the depressions may be sharp and brief, limited in area, and followed in a few months by renewed periods of prosperity. To this group would fall many minor depressions, for example, 1825, 1884, 1903 and 1914. Again, we seem to have a group of panics which have lasted approximately two years and of which the one in 1857 was undoubtedly the most notable. To a distinct class would fall the five years of depression that followed 1837, 1873 and 1893. Some one with great confidence in superficial historical analogies might even be found to argue that after two years of gloom the third year of a panic will be marked by flickering movements in the indices of prosperity, in which alternate despair succeeds to hope; that in the fourth year, the signs of returning prosperity are at once more numerous and more evident; and that the fifth year will come to benefit both the American people generally and those political groups which at the time are in a strategic position to capitalize the return of the full dinner pail. But experience has after all been too brief to tempt the cautious into the field of prophetic generalization. Under altered conditions, there seems to be no good reason why other categories of different length may not, and soon, be added to those which roughly describe the length of American depressions.

Conditions change so rapidly that it is unlikely that any theory of panics will be entirely satisfactory for more than a single decade. And yet, from even this cursory and unsatisfactory review of the chief American panics and depressions, different as they have been in many of their details, a few generalizations seem at least tentatively possible. In the first place, every panic of which we have any record has had as an antecedent condition a process of investment in lands, ships, goods, stocks, notes or other securities from which the investor has expected at least a return and often an unreasonable profit. Some of these investments have been virtually compulsory, as in cases where modern people have capitalized the very wastes and losses of great wars; again they have been obviously shortsighted, as in the case of the canals of the thirties and again in our own day in foreign investments in countries that were virtually prohibited by increasing tariffs from returning either principal or interest on their debts; others, still, have been marked by obvious elements of wasteful fraud, as in the case of the railroads of the seventies; and some finally have been ultimately wise and even socially beneficial, but have anticipated somewhat too eagerly the demands of a slowly rising population. But whether the investments have been compulsory, dishonest, absurd or even wise, the day of reckoning has come when the debtor has proved unable to pay, and the panic itself seems without exception to be the immediate result of the effort on the part of creditors to collect bad debts. For this reason one of the persistent features of panics has been an increased consciousness of kind among creditors and debtors alike, either individuals or nations, sometimes, as in Bacon's rebellion and the uprising of Daniel Shays, leading to armed conflict and again, as in the march of Coxey's army, ending in complete fiasco. These depressions have usually been hastened and made more severe by elements of uncertainty in monetary systems, in tariffs or in diplomacy, to such an extent that in contemporary discussions these occasions of a panic have more than once come to occupy the center of the stage.

Now, if the causation of panics has been even roughly sketched, the other side of the equation is at least equally significant and has been too much neglected. For from these panics have come social consequences, using the phrase in its largest sense, which have not been entirely dissimilar. In America at least, one of these has been a large movement of population, like the westward movement of the early panics, and another has been the emergence from the conflict of the times of new and significant institutions, of which the Federal Reserve Act, the Independent Treasury System and even the Constitution of the United States may be regarded as examples. It is by these and other similar social consequences that the modern historical emphasis on these periods of depression is to be chiefly justified.

For, if bad investments and uncertainty have been the two common factors in the origination of panics, it is well to remember that no one of these has proved to be like the depressions of the ancient world either hopeless or without incidental advantages. In every American panic, the path of escape has been found in the very conditions of the depression itself. By the acceptance of the lower price level, by the removal of uncertainty, sometimes by the discovery of wider markets, where luck and foresight have both sometimes contributed, by enforced economy, by writing off bad debts, the foundations have been laid for still another period of prosperity.

The most discouraging feature of the whole story is that in the last experience, in spite of a well-organized banking system and of immense resources, both natural and acquired, in spite of all its vaunted business sagacity, with almost no accidents to furnish an excuse, America, by following at the same time two contradictory policies regarding her tariffs and her investments, has deliberately walked in a path which seemed to court inevitable disaster. The history of ancient and medieval panics is often a monument to human misfortune; that of modern panics, in which the last is surely no exception, are a supreme monument to human greed and to human folly. Let us trust that even this one will serve its function to arouse public opinion to unrecognized conditions, to change accepted formulas, and to introduce in both production and in foreign commerce methods which are suitable to a new age.

EROSION ON UNCULTIVATED LANDS IN THE INTERMOUNTAIN REGION

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It is a comparatively short time since the white man occupied the western half of the United States. Of this vast region only a limited area is, or probably ever will be, tilled. In contrast to the eastern and middle western states where the soil is used largely for the growing of cultivated crops, large parts of the West are now and perhaps always will be utilized principally as range land for the grazing of domestic live stock. Some of these lands have been grazed about 80 years, but most of them only about 40 to 50 years. During this relatively brief period, on account of our limited knowledge and due to the unhappy results of little managed grazing and unrestrained competition in the use of the open public lands and absence of fire suppression, there has been a marked depletion in the native plant cover and a consequent erosion of the soil on extensive areas. On the ability to recognize and correct this unfortunate situation depends much of the future welfare of the region, for once the soil is depleted by erosion generations may be necessary to restore its productivity.

The term "erosion" is here used to designate the washing away of soil at a materially more rapid rate than the constructive or restorative processes allow for soil accumulation and improvement. On steep slopes, never too well clothed with vegetation, there has always been a downward movement of the soil. Under normal undisturbed conditions such as prevailed before settlement this loss on most of the land was not in excess of the additions made to the soil by the processes of weathering and of the decay of plant materials. Had this not been the case, the slopes centuries ago would have been denuded to bedrock. The normal rate of geological erosion in most places was such that the constructive processes were equal to or slightly superior to the destructive. In other words, there was a balance in soil depth and quality established, which, except for subsequent abnormal erosion, would have produced a present soil condition somewhat better than that which occurred at the time of white occupation. Certain exceptions perhaps are the deeply dissected country of the Colorado River drainage and some other places where the normal geological erosion has been and still is enough more active to maintain unstable conditions. Present concern, however, is apart from the natural processes. It has to do with the areas where there is considerably accelerated removal of the better soil concurrent with fire and overgrazing during the past 40 to 80 years.

The Intermountain Region to which this discussion specifically refers, comprises all of Nevada and Utah, that three fourths of Idaho which lies south of the Salmon River, about one fourth of Wyoming west of the main chain of the Rockies, and Arizona north of the Grand Canyon. The major physiographic units are (1) the Great Basin occupied during the last glacial epoch by the prehistoric lakes Bonneville and Lahontan, (2) the area drained by the northern and western tributaries of the Colorado River, and (3) the Snake River drainage basin, together with the area

CHECK DAM IN MANTI CANYON, UTAH,
CONSTRUCTED TO CONTROL FLOODS AND DEBRIS FROM AN OVERGRAZED WATERSHED.

drained by the southern tributaries of the Salmon River.

LAND CLASSIFICATION

The total land area is approximately 184½ million acres in extent. Of this only 3 per cent. is cultivated. Probably not to exceed 6 per cent. ever will be tilled on account of its limited water supply, its rough topography, or its shallow soils. Somewhat less than 11 per cent. is commercial timber land, of which one fourth, or a little less than 3 per cent. of the region is too dense for grazing. In other words, the Intermountain Region is predominantly a grazing territory, with comparatively small areas devoted exclusively to timber or to either irrigated or dry farm agriculture. However, about 10 or 11 per cent. is not grazed due to being waste, either barren or inaccessible. There is, therefore, approximately 139 million acres of strictly grazing land and 15 million acres of grazed timber land, which brings the grazed area up to about 154 million acres, or 84 per cent. of the whole.

Some of the most important watersheds in western United States lie in the mountains which fringe the intermountain plateaus. Although much more of the area is watershed from which flow temporary streams, some 30 million acres, or about 16 per cent., is properly classified as producing permanent streams. This area is made up approximately as follows: Five million acres of dense timber not grazed, 22 million acres of open timber and other range land, and 3 million acres that are protection forest or barren. Protecting this watershed land against erosion to maintain the quantity and quality of the water supply for irrigation and other use is a paramount problem in the region.

Not only is the region one primarily devoted to grazing, but the grazing industry is largely dependent on public lands. More than 75 per cent. of the whole region is still in federal ownership with at least another 10 per cent. state-owned. Of the federal land in the region, 100 million acres, or 54 per cent. of the whole, is open public domain.

This is approximately half of the entire uncontrolled public domain left in the United States. An additional approximately 10 million acres is federal mineral or other withdrawal with the surface right left to unrestricted free use. Another 29½ million acres is National Forest land.

Careful estimates placed the reduction in forage yield on the open public range during the 40 to 80 years of settlement at 50 per cent., or thereabouts. This figure is too high for some parts but in other areas there has been a destruction amounting to 75 to 90 per cent. During the quarter-century of administration by the Forest Service, there has been a 10 to 25 per cent. recovery on most of the National Forests, but the public domain has probably continued to decrease in productivity during this same period. On local areas of National Forest land where the soil was badly eroded prior to regulation there has been no improvement in forage production since control was inaugurated. Recent study has revealed that soil erosion is usually active under certain conditions on the loose granitic soils on some of the National Forests in Idaho. A series of general studies and three detailed investigations have shown destructive erosion to be wide-spread in the region.

EROSION STUDIES

Davis County, Utah, Watersheds

The summer just ended has pointedly called attention to present imminent danger of local floods accompanied by heavy erosion in Utah. In the general vicinity from Salt Lake City to Ogden, there occurred a series of over a dozen floods which cut great gullies in the hillsides and covered high-priced farming lands and highways with rock, gravel, sand and other débris from one to several feet in thickness. The soil on this watershed is largely sandy loam of mixed origin, having weathered from

EROSION DEPOSITS

AT THE MOUTH OF A SMALL STREAM TRIBUTARY TO THE ARROWROCK RESERVOIR, IDAHO. SEDIMENT TO DEPTH OF OVER 18 FEET HAS BEEN WASHED FROM THE OVERGRAZED SLOPES OF THE WATERSHED INTO THE RESERVOIR IN FIFTEEN YEARS OR LESS.

well-consolidated granite. It has moderate water-holding capacity and holds together moderately well.

The destructiveness of these floods resulted almost entirely from the soil, rocks and other débris eroded from the mountain sides and canyons. Numerous boulders, up to 300 tons in weight, were carried far out in front of the mouths of the canyons. Several dwelling houses were swept away or filled with earth and rocks, orchards on land worth $600 to $800 an acre were covered irreclaimably. It cost approximately $100,000 to open and repair the highways alone and finally the watersheds are left in such a condition that there is danger of repetition of the floods with every heavy summer shower of any magnitude. Similar mud-flows and floods occurred in 1923 for the first time since settlement of the region.

Meteorological records show that at fairly frequent intervals the summer rainfall is of a torrential or semi-torrential nature, as is true of arid regions as a whole. The rains of August 13, 1923, and of July, August and early September, 1930, were unusually torrential for the region. There is no reason, however, for assuming that equally heavy storms have not occurred many times during the last several thousand years, although there are no indications of equally frequent floods such as occurred in 1923 and 1930. At any rate, much more apparent reasons for the recent outbreak of floods are found in the depletion of the plant cover.

An examination of the mountain front which rises from an elevation of 4,800 to 9,000 feet in a distance of 4 miles, from which the water and débris came, clearly established that the floods originated on the denuded upper limits of the slopes. Gullies began where heavy overgrazing by sheep and cattle, along with occasional brush fires, had removed most of the plant cover. Groves of aspen had been stripped of their reproduction as high as sheep could reach. In comparatively large areas a few large specimens of sagebrush (*Artemisia tridentata*) and niggerhead (*Rudbeckia occidentalis*) were practically all the vegetation left. Since neither of these species can develop on poor soil, it is concluded that such areas had been well clothed with vegetation typical of similar sites not so abused. Gullies began in these denuded spots and concentrated in the natural ravines. In a typical case there was a gully starting near the drainage divide that had been washed to a depth of 25 feet within 200 yards of the summit, showing how quickly the water concentrated in denuded areas. Interspersed areas, covered with a dense stand of little grazed chapparal, or patches of grass-brush land inaccessible to live stock but otherwise similar in character to the denuded land, were not eroded and showed no indications of flashy run-off.

Farther down the mountain side on much steeper slopes, and on the slopes of the main canyons, there is a good covering of oak brush and other vegetation. No gullies led from such areas into the ravines. There were, however, a few small denuded spots resulting apparently from burns. The fact that gullies were washed on these nearly bare areas showed that the rainfall had been as heavy over the brush-covered slopes as on the denuded areas above.

The water and earth débris from the feeder gullies on the denuded land above once concentrated in the main canyons, poured through the oak zone. The canyon bottoms were gutted to a depth and width of 50 to 70 feet. When the floods reached the lower gradients at the mouths of the canyons, they spread across the benchland and out upon the valley farms with the results mentioned.

Detailed Erosion Area Studies

Since 1912, the research branch of the U. S. Forest Service has maintained at

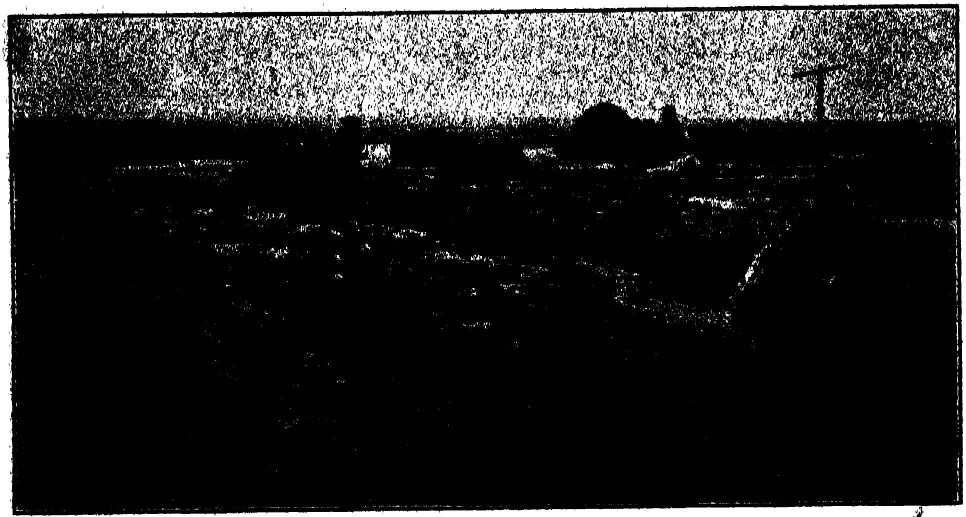
BOULDERS UP TO 200 TONS IN WEIGHT

WERE TRANSPORTED LONG DISTANCES OUT IN FRONT OF THE MOUTHS OF STEEP CANYONS BY THE FLOODS OF 1930 IN UTAH. THE LARGEST BOULDER CARRIED BY THESE FLOODS, IN AN ADJACENT CANYON, WEIGHED APPROXIMATELY 300 TONS.

the Great Basin Branch Experiment Station on the Ephraim Canyon watershed of the Manti National Forest a detailed study of the relation of vegetative cover and grazing to surface run-off and erosion. This is in a locality 10,000 feet above sea-level, where the annual precipitation, more than two thirds of which is winter snow, is about 30 inches. Two somewhat equal drainage areas distinctly different in degree of plant cover were placed under control and the water led through covered settling tanks equipped for measuring the water and eroded material. Rain gauges on the two areas measure the rainfall from each summer storm, and in later years tipping-bucket gauge records have been obtained to determine the rate of fall as well as the amount. The two watersheds, 882 feet apart, are subject to the same climatic influences.

The soils of both areas originated from limestone and shale. The raw unweathered soil is fine-particled, very adhesive when wet and having a granular-fragmental structure when dry. Where undisturbed, as on most of the well-vegetated area, designated as B, the surface soil is dark-colored and rich in organic matter to a depth of 3 to 6 inches. Beneath this is a layer of from 4 to 12 inches of friable clay fairly rich in organic matter and plant food. The second area, designated as A, was considerably eroded when the study began and has since been further eroded. On the latter plot the two upper layers of soil had been eroded to such an extent as to expose a raw inert clay low in organic matter and plant nutrients and very favorable to rapid run-off. A soil survey showed 65.7 per cent. of the depleted area A badly eroded, whereas on the well-vegetated plot B only 11.5 per cent. of the area had been so denuded of its surface soil.

Area B has had throughout a plant cover occupying 40 per cent. of the surface of the ground and the other from



LARGE AREAS OF HIGHLY PRODUCTIVE ORCHARD AND FARMS LANDS IN UTAH WERE COVERED WITH DEBRIS TO A DEPTH OF SEVERAL FEET BY FLOODS DURING 1930.

1912 to 1919 had a cover of 16 per cent. Between 1919 and 1924 area A was so treated that its plant cover was built up to 40 per cent. at which level it was kept until the present. There are available for comparison data for two periods, one of 6 years from 1915 to 1920, inclusive, when area A with a 16 per cent. plant cover is compared with B which has an old plant cover of 40 per cent.; and a second 6-year period from 1924 to 1929, inclusive, during which period area A with a newly acquired 40 per cent. cover is compared with area B with the old 40 per cent. cover. In addition, the run-off and erosion from melted snow is compared with the run-off and erosion from summer rainfall in seven of the years.

Sampson and Weyl[1] compared the productivity of non-eroded with that of eroded soils on the two areas. Wheat, peas and native brome-grass were grown in the two soils. They found it required from 2 to 8 times as much moisture to produce an equal amount of vegetable matter, dry weight, on the eroded soils as on the non-eroded. A bulk analysis of the eroded soil showed only 45 per cent. as much organic matter, 35 per cent. as much nitrogen and 67 per cent. as much phosphorous as on the non-eroded soils.

There were each year two fairly distinct periods of surface run-off, one of rainfall from July to September, inclusive, and the other of melted snow from late April to June, inclusive. During the first 6-year period, while area A had a 16 per cent. cover of vegetation, the summer rainfall run-off averaged approximately 913 cubic feet of water and 134 cubic feet of sediment to the acre annually on the depleted area as compared with 153 cubic feet of water and 25 cubic feet of sediment to the acre annually on the well vegetated area.

Only 4.6 per cent. of the total annual run-off from the plot with a 16 per cent. cover was from summer rains as compared to 95.4 per cent. from melted snow. The 4.6 per cent. which was summer rainfall run-off, however, carried an average of 80.1 per cent. or about five times as much of the sediment eroded annually as did the 95.4 per cent. melted snow run-off. With the same rainfall, the depleted plot during the summer rainfall period, produced 5.96 times as much run-off per acre and 5.42 times as much sediment as did the well vegetated area.

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[1] A. W. Sampson and Leon H. Weyl, "Range Preservation and Its Relation to Erosion Control on Western Grazing Lands," U. S. Dept. Agri. *Bull.* 675 (1918).

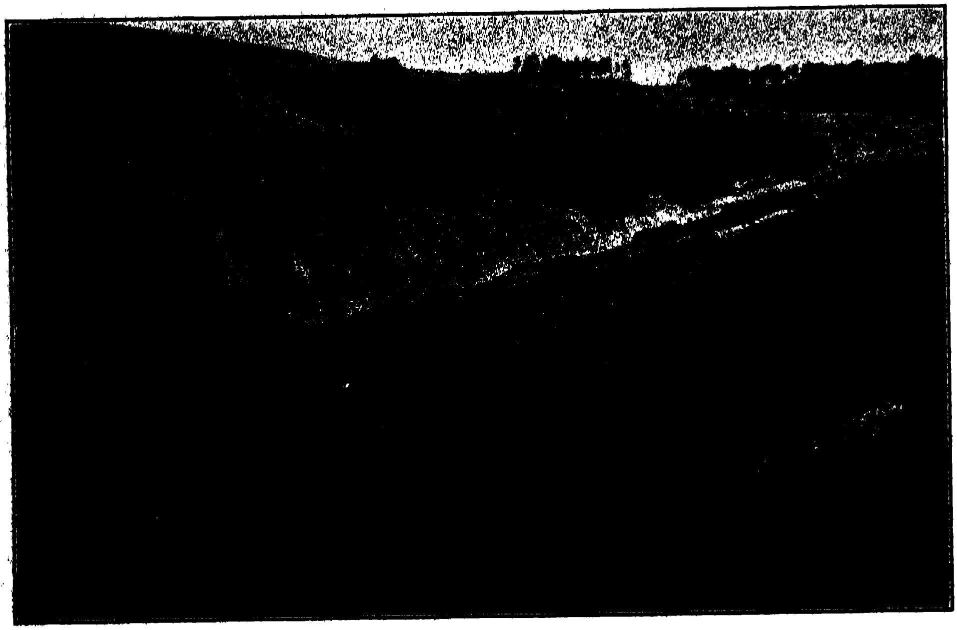
Between 1920 and 1924 the depleted plot improved to a 40 per cent. cover of vegetation and during the five-year period, 1925–1929, the formerly depleted plot had a cover equal in density to the other plot. It was, however, a newly established cover and had still a soil with most of the qualities it formerly possessed as an eroded plot. The surface run-off from summer rainfall from the older vegetated area was 137 cubic feet of water per acre, almost identical with the run-off for the period 1915–1920, but the sediment was only one third as great. The newly vegetated area showed the effect of the increase in cover by a reduction in summer rainfall run-off from 913 to 297 cubic feet per acre. This, when properly equated against the difference in rainfall during the two periods, is a decrease on the newly revegetated area of 63.8 per cent. in surface run-off due to increasing the vegetation from 16 to 40 per cent. of a complete plant cover. The run-off was still 2.16 times and the sediment 2.48 times as great from the newly vegetated plot. Part of this difference is due to greater slope, part due to better developed gullies, and part due to the lack of organic matter in the surface soil. Unfortunately it is not possible to give these three factors their exact weighting, as each influences run-off and erosion. The increase in cover did not influence the quantity of run-off in the spring from melted snow.

The sediment carried off each acre by summer rainfall run-off of the newly vegetated area averaged approximately 19 cubic feet annually, which is only one seventh as much as the 134 cubic feet which occurred in 1915–1920. When properly equated against the reduction in erosion from the older vegetated plot, there was a decrease of 54.2 per cent. due to increasing the vegetation from a 16 to a 40 per cent. cover. The erosion due to melted snow run-off was reduced 57 per cent. as a result of increasing the plant cover.

Erosion on Granitic Soil

Preparatory to a thorough-going erosion experiment now being started on the Boise River watershed in central Idaho, an examination of the soils has been made in 40 to 50 places which indicate that erosion has been very active in places on the loose granitic soils of this watershed. The herbaceous plant cover has been materially reduced in recent years, probably on account of a series of dry years, heavy rodent infestation and overgrazing by live stock.

In about a dozen places the soil examined was intact and well-preserved. On the upper part of the Fall Creek drainage, a tributary of Boise River, there was found a site of 10 to 15 acres of deep fine soil. The surface 6 inches is fine, black and rich in organic matter. At a depth of from 6 to 18 inches is a layer of fine gray-brown soil apparently rich in available plant nutrients and relatively high in organic matter. From 18 to 30 inches is a coarse gritty, sandy loam, beneath which is 10 inches of coarse sand on top of disintegrated granite. There are thousands of acres that were somewhat similar on parts of Fall Creek, Smith Creek, Slater Creek, Trinity Creek, Roaring River, and other tributaries. Except for small islands of good soil mostly less than an acre and frequently only a few square rods in area, the layer now exposed on the surface in these locations is the infertile, gritty layer that occupied the 18- to 30-inch depth profile on the good site on



THE SAME AREA AS SHOWN IN ADJACENT PHOTOGRAPH IN 1925, AFTER 15 YEARS OF REGULATED GRAZING. VEGETATION IS SLOWLY HEALING THE SCARS OF DENUDATION.

Fall Creek. Of course the two top layers of good soil originally were not everywhere as thick as on Fall Creek. They probably varied from an inch or two to the 18-inch section studied. There seems only one justifiable conclusion, namely, there has been a wholesale loss of the more fertile top soil. Allowing for extraordinarily steep slopes, rocky areas and ridgetops, which probably never were well covered, at least half of the open grazed area is heavily injured due to loss of the highly productive top soil, exposing the loose gritty subsoil which is not particularly fertile. No observations were made in the timbered or brush-covered areas.

A survey of a body of approximately 129,000 acres on the watershed in 1929 indicates that serious erosion to the extent of deep gullying is occurring on 2 per cent. of the area, fairly serious erosion on 15 per cent. of the area, and sheet and light gully erosion on 56 per cent. There is no noticeable erosion on the remaining 27 per cent. which is mainly covered with dense timber or brush.

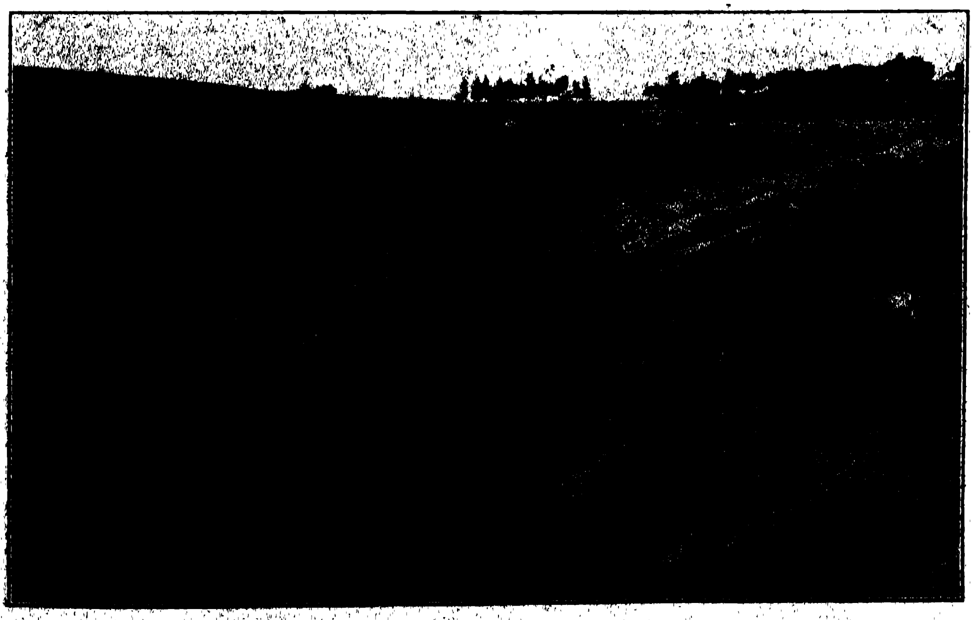
A further indication of abnormal erosion on this watershed is the accumulation of excessive gravel and sand deposits at the mouths of some of the smaller tributaries of the Arrowrock Reservoir and a layer of one inch to a foot in depth of fine black silt high in organic material over most of the bottom of the storage basin. Between 1912 and 1927 from 7,000 to 8,000 acre-feet of material was deposited in the reservoir which originally had a storage capacity of 276,000 acre-feet.

GENERAL OBSERVATIONS

In addition to the cases studied specifically, there are many canyons and mountain valleys that show unmistakable evidences of a recently greatly accelerated rate of erosion. In Utah there are probably hundreds of such cases, three of which will be reviewed briefly. These are Kanab Creek and Long Valley in the southern end of the state, and Price River, all draining areas covered with a fine sandy soil derived largely from sandstone.

Kanab Creek is a small stream which formerly flowed harmlessly down its canyon and out over a strip of good farming land, emptying directly into the Colorado River a few miles below Bright Angel. It meandered back and forth between banks lined with willows and grass. Nowhere was there any gully to speak of. As late as 1895, a man could, except during the periods of freshet, hop from one bank to the other. Then overgrazing and untimely grazing became common on its small watershed and along its banks. The vegetation on the land adjacent to the channel was further broken by cultivation, roads, etc. In a few years a gully was cut to a depth of about 50 to 100 feet, and from 100 to 300 feet in width. Side gullies are now working back into the farming land and into the public domain lands of the section. The canyon bottom throughout most of its lower reaches is swept practically clean of soil, bedrock being exposed almost continuously.

Across the mountains from Kanab Creek and some thirty miles northwest, one of the upper branches of the Rio Virgin flows through Long Valley. In the early days of settlement in Utah this valley was occupied by a series of colonizing groups. The valley, though only from a quarter to a half mile in width throughout much of its length, was highly productive. Under intensive irrigation agriculture, supplemented with range live stock, the people lived in moderate circumstances. Simultaneously with disastrous erosion on Kanab Creek, the stream in Long Valley rose repeatedly to freshet proportions and gullied a channel the entire length of the valley. For at least 20 miles the gully is 10 to 30 feet deep and is widening during every heavy storm by undercutting and caving. Perhaps



THE HEAD OF A SMALL MOUNTAIN STREAM IN CENTRAL UTAH, IN 1910, BADLY DEPLETED OF VEGETATION BY GRAZING AND DEEPLY ERODED.

a fourth of the fertile soil is already gone. Farther down the Virgin, below Little Zion Creek, in the wider valley of the upper Virgin, is Rockville, a farming community of some proportions which has lost more than half its soil to a depth of 10 to 20 feet or more. There is no evidence of an immediate let-up. This condition, thought to be due to uncontrolled grazing on the public domain lands, is wide-spread on the northern and western tributaries of the Colorado River. What this will mean to the storage capacity of the reservoir to be created by the Hoover Dam is easy to conjecture.

A few miles above Price, Utah, on still another branch of the Colorado, some 200 miles to the north, Gordon Creek flows into Price River. In 1900 this canyon had a gently rounded bottom and a stream that meandered. Destructive freshets were either unknown or so uncommon as scarcely to be noticed. Many times in the last ten years floods have poured down Gordon Creek, destroying on two occasions the irrigation flume supported on a high trellis across the recently eroded gully now a hundred feet deep and 400 feet wide. Nearby, at Castlegate, the main line of the Denver and Rio Grande Western railroad twice in the last decade has been covered with boulders weighing 10 to 50 tons. Automobile highways leading east from Castlegate up Willow Creek and northwest up Price River Canyon have lost their bridges and great sections of the road grades at least every second year during the last decade. Price River, in 1927, had high water or floods twenty-five times and bridges were washed out three times, between June and September. The railroad was either impassable or capable only of emergency use for weeks. Within a radius of 30 miles from Price there are at least 50 major gullies.

PLACE OF VEGETATION IN PREVENTING SOIL EROSION

Research data presented from the permanent run-off and erosion study areas at the Great Basin Branch Experiment Station, from the detailed field studies on the Davis County, Utah, watershed, and from granitic soils in Idaho show that perennial vegetation plays a leading rôle in the prevention and control of soil erosion, and even has a great deal to do with reducing or preventing the destruction by floods in the Intermountain Region. Given an opportunity on depleted and eroded range areas, vegetation will begin to heal the gullies and lessen the injury caused by erosion. It is not perhaps possible in the present status of our research information to list all the ways in which vegetation may control erosion and prevent serious floods. However, several of the contributions made by plant cover toward soil stability have been clearly manifested.

(1) As Lowdermilk[2] has demonstrated, the organic litter itself in or on the surface of well vegetated soils absorbs water, but primarily keeps the underlying soil opened to rapid and deep percolation, whereas with bare soil the interstices are soon sealed up by the fine soil particles carried in the run-off, thus decreasing the rate of absorption and increasing surface run-off.

(2) Observations on the Davis County watershed in Utah, on the granitic soils in Idaho and elsewhere make it clear that the accumulation of run-off from torrential rainstorms into streamlets and the formation of gullies on slopes is very much in inverse proportion to the density of plant cover. On heavily vegetated slopes with a natural accumulation of plant litter there

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[2] W. C. Lowdermilk, "The Influence of Forest Litter on Run-off, Percolation and Erosion." *Jour. Forestry*, pp. 474–491, April, 1930.

was not sufficient surface run-off from the semi-torrential storms of 1930 to leave a trace of gully erosion. Where there was moderate vegetation the water accumulated in streamlets and began to cut for short distances, but the vegetation, both the living plants in place and the accumulated dead material on the surface scattered the streams, caught the soil that had been picked up, and prevented the accumulation of the streamlets into currents of gully-washing proportions. In other words, moderate vegetation kept the water always in driblets and prevented torrents. Where the vegetation had been heavily depleted, the streamlets accumulated into larger currents and these into torrents that traversed the slopes from top to bottom and gouged gullies that varied from small "shoestrings" near the top, to washes 10 to 20 feet or more in depth at the bottom of the slope.

(3) The roots, and to some extent the tops of perennial plants, actually bind the soil and hold it in place against erosion.

(4) Once begun, floods and erosion form a sort of vicious circle. In the beginning surface run-off makes gullies, but after that the gullies permit such a rapid accumulation of surface run-off as to become an important agency in the occurrence of floods from heavy rainfall of short duration.

Moreover, the sediment carried by water becomes a tool of abrasion. The rocks in the bottom of the river just above Niagara Falls are covered with moss and algae. The same is true of mountain streams from well-vegetated watersheds. Let the stream become turbid for a few hours and the sand driven by the current rasps the rocks clean. Sand and gravel borne by a current cut rapidly whereas clear water has little effect.

The volume of a flood is considerably increased by the earth carried by the water. If 5, or 10, or 20 per cent. of flood as it comes off a slope is silt, sand, gravel, stones, and other débris, the volume is just that much greater.

(5) Falling water on well-vegetated slopes is retarded in its downward movement. Delay of a few minutes permits percolation to become of consequence. Delay also distributes the run-off over a greater period of time, thereby avoiding the formation of great heads of water which gain enough velocity and, with sediment, enough cutting power to rip out gullies and roll great boulders. A stream from a well-covered watershed may have either no high water or may distribute it over several to 24 hours, whereas a similar storm on the same watershed after it is denuded and gullied may all run off in from a few minutes to an hour.

(6) As shown in the depleted experimental erosion area, an increase in vegetation soon catches soil in the bottoms of the small gullies. The soil loss was decreased in three years to such an extent that the sides and bottoms of the gullies from one to four feet deep were noticeably in the healing stage.

A NUCLEAR CENTURY[1]

By Dr. LESTER W. SHARP

PROFESSOR OF BOTANY, CORNELL UNIVERSITY

> In eighteen hundred and thirty-one, just one hundred
> years ago, Robert Brown, the celebrated British
> botanist, announced his discovery of the nucleus.

I am the nucleus!
The world of organisms is my spacious stage:
In toads and toadstools, cycads, cabbages and kings
I play my myriad rôles.
Without my will, kings were not regal, tadpoles toads,
Nor Brassica your sustenance.
Before you in a million representatives I lie
Like karyoplasmic star dust in a universe of cells.
In each of you is some per cent. by weight of me;
So, Homo, canst thou "know thyself" unless thou know'st thy nuclei?
But not to boast I come to-night:
'Tis rather to salute you on a hundred years' acquaintance.
Accept, I pray, this brief recital of my own experience
While yearning for discovery and striving for position
In the sun of human understanding.

PROPHASE

Long, long ago, in times remote beyond the span of mind, the earth,
New-made but old, through chilly space its lifeless course pursued,
Led onward by a flaming star whose genial rays
Brought promises to lake and soil and saline sea—
Inorganic desolation's home: so rolled the planet on.
How came my kind upon the scene I can not tell.
Tradition holds that in some ancient sea the sun
By unsuspecting colloids did beget a prodigy—
A primal, autocatalytic slime which hopefully respired.
'Tis said, as eons came and went my elements did aggregate
To function with a new consistency;
And there, behold, was I!
'Tis also guessed that I lived first and somehow round about me
Synthesized my cytoplasmic dwelling place.
The truth, I fear, is lost; can you, O Homo, self-styled sapiens,
Discover where it lies?
Too long for but a single night, the story of my endless struggle
Aiding organisms in their long unfolding—
The ordering of my parts; the mergers, losses, rearrangements;
Resistance and submission to the force without;
The trials and errors numberless which went upon the rocks
Where you who run may read them.
Through all my fortune's fluctuations did I keep the faith

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[1] Presented as the address of the retiring president of the Botanical Society of America at its annual banquet in New Orleans, December 30, 1931.

Until from time's slow toiling mill there came,
Far up from slimehood's low estate, that crowning trio:
Fruit fly, maize and man.
In Asia, old Neanderthal and Crô-Magnon
You made your epic rise, not knowing of my aid.
With blades of fair Toledo and Damascus
Sectioned you yourself and me, yet saw me not.
Such rude technique could never serve for my disclosure;
Savagery was ever deaf to messages like mine.
I felt a warming ray of hope when men of peace
Began to fashion glass to aid their feeble eyes
And peer about them curiously.
In Holland, England and the sunny south I fell
Beneath the microscope's cold, glassy stare.
Within pellucid cells displayed I all my nuclear charms,
Entreating your acquaintance.
"It will not now be long," I thought, as o'er me swept
The glances of Van Leeuwenhoek, Malpighi, Grew, et altera,
And later, of Purkinje, Meyen and Brongiart;
But one and all they turned away to treat of lesser things.
So passed the fruitless years away, and ever lower, deep despairing,
Sank within me my nucleolus.
Then came at last the day. 'Twas in an orchid leaf,
Where I, with silent diligence, engaged in forty foliar functions;
'Twas there, with light upwelling from below,
I felt an influence run me through—a keen and penetrating thing
Like some new cosmic ray.
I sought with eagerness its source, and darkly through the glass above
Descried the eye of Robert Brown, "botanicorum princeps."
Steadily it gazed, and with a cast of thought;
It roamed o'er all the tissue searchingly,
Yet always came to rest on me.
The epidermal cells intrigued the searcher most
(In them I did look rather well);
He saw me also in chlorenchyma
And in the hairs which clothed the surface o'er;
And then, convinced that I should speak to all mankind,
He wrote his brief but cytoclassic record.
Ne'er will fade the memory of the thrill which ran
Through every fiber of my tense reticulum;
An age-long hope was coming to fruition!
How my membrane palpitated!
Every tiny microsome rejoiced with me
In dizzy Brownian dance!

METAPHASE

Through the eyes of Robert Brown and those who followed him
There came to me a new and rich experience,
To you the promise of advance undreamed of (save alone by me).
Harken to the words which introduced me to your world of men:

"In most Orchideae each epidermal cell contains
A single round areola, convex and granular, and lying variously.
Now this areola, or nucleus, as we perhaps may say,
Is not confined to epidermal cells,
But shows itself in divers other places, even in the pollen.
Nor is it to Orchideae peculiar:
Lilies, asphodels and other monocots display it, too.
Not often in the dicots is it evident,
Though in maturing microspores it may perhaps exist."
How quaint in retrospect this utterance of other days!
How meek a mighty river at its source!
Had what I've told been all,
No message of commemoration would I offer unto you;
No pseudopoem would you now endure with gracious charity.
Not only did you see afar the borders of a strange, new land,
But you approached it with courageous, if uncertain, step
To make its treasures known.
No sooner had you dubbed me "Nucleus" (imagine, "Little Nut"!)
Than you began to press me, as between the cracker's jaws,
To ascertain the secrets of my inner life
And publish them abroad, as is the wont of men.
"How come the nuclei to be, and how the cells?
I'll tell you how it is," exclaimed the fiery Schleiden;
"All who disagree with me are wrong, and what is more,
Incapable of being right! 'Tis thus:
Within the limpid liquor of the cell
A granule forms by simple condensation;
Other granules cluster round and form a cytoblast;
A vesicle upon the cytoblast takes origin and swells,
Engendering a cell anew within the parent cell."
Though pleased to be assigned a rôle in cell formation's drama,
Vexed was I by Schleiden's strange opinion of my playing:
I, a heap of granules innocent of ancestry!
The cell, a cytoblastic blister!
Such phantasies, though doomed to early death,
Sufficed for Schwann's far-reaching theory,
Which later lived without them.
Their fate was sealed as they were born
By Unger, Nägeli and the great Von Mohl,
By Kölliker, Remak and all the rest
Whose names still live for you and me.
More deeply did these men of patient and attentive mind
Appreciate the import of the spectacle before them.
They saw the reproductive paradox enjoyed by nuclei and cells—
The way we multiply by just dividing,
Each yielding up his self to two, these two their selves to four,
The four to more, and so ad infinitum.
'Twas we who labor for the good of men,
And not some little corporal, who first exclaimed,
"Divide and conquer!"

Fraught with deep significance for you
Were many features of this metaphasic period,
But none held greater promise than the gradual discovery
Of life's colloidal hiding place,
When science took the slime rejected by the old anatomists
And placed it at the head of cell research's corner.
Ever fairer with the passing years
Grew human views of protoplasm, cells and me,
Until Max Schultze's able pen proclaimed
The cell a protoplasmic entity,
Its parts arising by division of their kind.
Slowly had I struggled to this metaphase of my career,
But now I seemed to feel myself all set, as on a mark,
For quickened anaphasic progress.

ANAPHASE

How am I, the nucleus, to sing the praises
Of Zellforschung's classic period—
That final quarter of the nineteenth century,
When first I took my rightful place among you?
Would that mine might be the words of Athens' ablest bard,
Or what is more, of him who writes your automobile ads!
My lonely progress toward discovery had ill prepared me
For the battle for my favor now begun by worthy men.
My rise in popularity, I fear I must confess,
Accompanied the use of artificial aids to beauty:
With carmine and with safranin my countenance was flushed,
While logwood brew (one-half of one per cent.) evoked my subtler charms.
To-night I seem to breathe again that osmicated atmosphere
And hear the measured music of the Minot microtome.
I seem to see a vision of those champions of mine
Who toiled to lay foundations firm for karyology:
Strasburger, Flemming, Bütschli, Hertwig,
Boveri, Fol and Van Beneden.
In those days were there gigas types;
How gigas, too, their legacy to you!
To minds prepared I gave the deeper secrets of my origin
And saw them shake the scientific world.
I taught them how in tissue cells 'tis always by division
That I propagate my kind; no other way I know.
From one spring all the soma's nuclei, a karyotic clan;
Whence now this one, progenitor of all?
In eggs of worms and angiosperms I next revealed to waiting eyes
An esoteric wonder: syngamic nuclear fusion.
This mutual self submergence ('tis an ancient nuclear custom)
Long has been my trusted means of self advancement:
I have divided, yes, but also have I fused to conquer!
I'm like a netted thread which runs throughout the living world
Uniting all through time and space in one vast family.
In all the century no weightier thing you learned

Than "omnis nucleus e nucleo."
Before the classic days of which I speak
Men claimed that I dissolved and formed anew in duplicate
Whene'er a cell divided. The keener sighted
Spied a group of bodies equatorial
But comprehended not the messages they bore.
Then came the famed "Zellbildung und Zellteilung" and the like,
Picturing my passage through the phases of mitosis.
They showed how my reticulum a thready form reveals;
How all the threads are doubled and become assorted rods;
How these go into metaphasic huddle, hesitate,
And then, the spindle guiding, go gliding to their goals,
Where once again they settle down to metabolic labor.
More public every year became the private lives of chromosomes
(A name you doomed my luckless rods to bear).
You founded gossip sheets with long and ponderous names
For stories of their strange behavior, actual and fancied:
Their number in the soma as it grows;
Their pairing and divorce in reproductive cells;
The greeting of their partners new in each succeeding zygote;
Their cautious march in embryogeny—
In chromosomal terms you wrote the cycle of the life
Of almost every sort of living thing
From lowly protist upward (as the saying goes) to man.
Of what significance, this drama so unfolded?
What mattered it to you, this syngamy, spiremic split,
Synaptic urge and chromosomal continuity?
'Twas syngamy that tempted with a clew:
A fusing gamete might be nought but nucleus
And yet endow the offspring with a worthy heritage.
Heredity now claimed in me a vehicle:
Behind my sleek sphericity I hid determiners
Employed in fashioning successive somas
Saved from dull monotony by amphimictic variation;
Thus, in speculation keen, concluded August Weismann.
So equipped with basic facts, new aids to hand and eye
And theories provocative of mental light and heat,
Your karyologists attained the nineteenth century's end.

TELOPHASE

Our joint adventure's latest phase was heralded
As by a star, which, after long eclipse,
Shines forth to guide the traveler aright.
Long years before, at Brünn, the Königskloster's abbott
Had told the tale of Pisum's progeny
And found for you the rule of one-to-two-to-one.
This simple beacon failed to penetrate the mists
Then drifting o'er the landscape of genetics
Till, the century complete, three wise men caught its beams anew.
Straight down its widening path of light they moved

To find deliverance from old obscurities
And add new luster to the name of Mendel.
The world now knows it was to me that you appealed
For explanation of phenomena displayed
By peas and mice and four-o'clocks;
It knows the story of synapsis and disjunction,
Diplosis wrought by blending syngamy
And all the other chromosomal deeds, somatic and meiotic;
It knows the evolutions odd
Through which I send my genoms ever cycling on
To be the new genetics' master key.
Ever wider swung the doors this key unlocked,
Admitting you to understanding new of coupling and repulsion,
Withering sterility, the embryo's resolve to bear
The spear and shield of Mars or Aphrodite's mirror.
Through many turnings of the genic labyrinth
Drosophila melanogaster led the way:
How typical of New World opportunity,
This creature's sudden leap to fame from off the pomace pile!
My ever growing prominence in world affairs
Required new portraits of my chromosomes
Still quaintly shown in public prints with eighteen-ninety lines;
But after men of Serge Nawaschin's skill had scrutinized them well
They showed more modern silhouettes,
With arms, attachment points and satellites,
While up and down within them crooked chromonemas ran.
Early was I called upon to demonstrate my strategy
In hybrid plants, where I, though equal to somatic matters,
Often felt embarrassed by synaptic diffidence:
My chromosomes forsook their old meiotic minuet
And danced alone in solemn univalence,
While I was saddened by the youthful spores I saw zugrunde going.
Long did I perplex you with my frequent polyploidy,
A puzzle cytoarithmetical in which you now perceive
A likely clew to species alteration.
Your vaunted analytic powers I tested with a special trick,
Segmental interchange, wherein my chromosomes
Joined hands in diaphasic chains and zigzagged in the anaphase.
You saw the point (when twenty years had passed!):
With Jimson Weed and Zea Mays you solved the mystery
When all were growing weary of the evening primrose path;
And then, to prove again your power, you wrung from me
The long awaited proof of chromosomal crossing-over.
Meanwhile other groups of men, commendably original,
Assailed my stronghold with another set of weapons:
Microprobes and Lilliputian squirt-guns,
Acids, whirligigs and vital dyes—
All these did I endure to further karyology.
They stretched me out between two pins and twenty-two opinions new
Concerning what I knew not that I had, pH.

I felt the X-ray's quivering urge suffuse me through,
Dismembering my chromosomes with no respect
For preëstablished order, like overzealous dust maids;
But in dismemberment they cast a vote of confidence
In strange hypotheses of linkèd genes
And moved a few amendments.
Behold therein how jolts from old routines
Evaluate familiar points of view!
So now I come to nineteen hundred thirty-one,
A century since my début, still young,
And with a will to point the way to ever greater conquests.
I hold the key position in a powerful alliance:
Cytology, genetics and a new taxonomy.
With you and me thus trebly armed to carry on
As artificial barriers dissolve in time away,
Who now shall stay our march?

INTERPHASE

The past is in the past; it's in the future, too:
Biology can never be as though I ne'er had been,
For what I taught you in the century just gone
Will color all your thoughts of life to-morrow.
To-morrow's thoughts! O whither will they carry you and me?
The doctrine of heredity so bravely built
On Weismann's daring plan must be the more refined
And made to yield a greater human service.
Concerning genes I'll strive to teach you more:
The nature of the things they are—and aren't;
The portion of my work for you they do—and don't;
How in metabolism's course they turn ontogeny;
The measure of their worth in evolution's grander schemes.
Be not content with inference from end results:
My whole life cycle, as I live it, must you know;
With keener methods must you probe my physiology
And search development for light upon heredity's enigmas.
'Tis homely, solid facts you need;
You'll know no dearth of speculative vapor.
With lenses, tissue flasks and subtle radiation,
And now and then a bit of cerebration,
You'll execute refined analyses.
Be sure analysis with integration joins
If you would know the organism whole and my position in it!
Through all this quest consider well the faithful cytosome
Who with me lives to forge our protoplasmic destiny;
The plastids, vacuoles and elements of doubtful pedigree
Are all my partners in the work of life;
'Tis we, not I, who build the race!
What men have learned is but a minor part of what I have to teach:
Could you perceive the Unknown's vast extent
You'd know the meaning of humility.
In every corner of my field is room for many tillers.

I fain would see outgrown with shame that staking out of claims
Which shows so well the end for which the work is done.
Fear not the duplication of your efforts!
Rather should each worthy task be thrice performed;
The truth you seek deserves security!
This many-sided venture, I foresee, will bring to sympathy,
If not to understanding, self-sufficient specialists
With souls corroded by a mutual suspicion.
The science of the living, like to that which lives,
Will prove itself to be a unitary whole,
And not until it banishes intolerance
Can it attain coherence in its own philosophy.
New knowledge brings to you new power, not always common sense.
As busy years which lie ahead speed hither to your service,
Will human right to be well born be met with opportunity
Like that enjoyed by pampered Bos and Equus?
Can anybody tell?
Will power to mould development be used with vision broad,
Or will the standardizer's baleful influence prevail
And bid you ever live with neighbors like yourselves?
And in your schools, will you who would enjoy your work,
As well as you who would employ the worker,
E'er escape the thraldom of the Ph.D.?
Will native worth be freed from ruddy ribbon's snares?
Such hopes are ever in me.
Will genes of wisdom dominate the potent genes of size and speed
Which, uninhibited, oppress your human kind?
Will values then be better judged than now?
I wonder, when a miracle of science
Stirs the ether mightily with sublimated piffle
And the dismal drivel of moronic song.
My courage falters when I see great trees I strove to fashion
Slain to carry fiction's flood of dirty ink.
I tremble for the future when I witness
Art betrayed by studied ugliness
And statesmanship by craven politics.
But optimism is a nuclear trait;
So far with you I otherwise could ne'er have come.
I've seen you rise and fall and rise again since I began;
So let another century of human effort roll its course
While I roll mine, expecting much and hoping for the best.
In that far distant day when hopes of supermanhood are fulfilled
And sapiens becomes a fitter name,
Recall, I pray, your ancient debts to me, the humble nucleus,
To Theodor of Würzburg and to Eduard of Bonn
And all the pioneering band who followed in the steps
Of Robert the Discoverer.

RESTING STAGE

THE APPALACHIAN TRAIL:

A GUIDE TO THE STUDY OF NATURE

By BENTON MACKAYE

ORIGINATOR OF THE APPALACHIAN TRAIL; VICE-PRESIDENT, REGIONAL PLANNING ASSOCIATION OF AMERICA

The best way to become acquainted with any scenery is to engage in some pursuit in it which harmonizes with it.—*Thoreau.*

THAT is why the Appalachian Trail was started—to become "acquainted with" scenery; to absorb the landscape and its influence as revealed in the earth and primeval life. The way to attain this is to do something, not just admire something. To engage in some harmonizing "pursuit"! To build a foot trail several hundred miles long through the scenery of the Appalachians on the crestline from Maine to Georgia: this is the first pursuit which several hundred young persons have accomplished during the past ten years. Such is their first long step in the longer pursuit of becoming harmonized with scenery—and the primeval influence.

Primeval influence is the opposite of machine influence. It is the antidote for over-rapid mechanization. It is getting feet on the ground with eyes toward the sky—not eyes on the ground with feet on a lever. It is feeling what you touch and seeing what you look at. It is the thing whence first we came and toward which we ultimately live. It is the source of all our knowledge—the open book of which all others are but copies.

What pursuit can we engage in, on the Appalachian Trail, "to become acquainted with" the scenery it traverses? That is the subject of this article. It is to learn how to read. How to read the "open book"—first hand, not tenth hand. How to read the story of the earth—a particular part of the earth—the Appalachian earth and the life thereof. The earth story is told in the structure of the Appalachian Range; the earth's life is disclosed in the forest on its slopes.

The forest indeed is a whole civilization: it is a close-knit society of plant and animal life containing every race alive save one. That one is man. He has made another civilization. He calls it "human society." Human society is an offshoot of forest society. Each has its history. To know America we must know human history, and to know humanity we must know forest history.

But the earth story precedes the forest story. One is contained in the Appalachian Range and the other in the Appalachian Forest. We can read them both—first-hand—from the Appalachian Trail.

THE APPALACHIAN TRAIL

The Appalachian Trail is a footpath on the crestline of the Appalachians stretching from Maine to Georgia: its projected length from Mt. Katahdin to Mt. Oglethorpe is estimated at 2,054 miles, of which about 1,400 are completed. Being a foot trail and not a motor road it traverses the highest and wildest portions of the mountains: the White Mountains, Green Mountains and Berkshires of New England; the Hudson Highlands of New York; the Blue Mountain Range of Pennsylvania; the Blue Ridge of Virginia, and finally the Great Smokies of Tennessee and North Carolina. It has been made (and is being made) by local clubs all along the line. It coincides in many places with the main trails of such local clubs which have equipped their sections with shelters and cabins.

The plan was proposed ten years ago as a "project in regional planning" in an article by the author which appeared in October, 1921. In 1925 the Appalachian Trail Conference was formed, consisting of a loose federation of all the local clubs. An executive committee of eighteen persons, headed by Mr. Myron H. Avery, now has the work in charge. The Trail traverses several National and State reservations (both forests and parks) and forms the backbone for projected reservations in between. The Appalachian Trail indeed is conceived as the backbone of a super reservation and primeval recreation ground covering the length (and width) of the Appalachian Range itself, its ultimate purpose being to extend acquaintance with the scenery and serve as a guide to the understanding of nature.

The first decade of the Appalachian Trail project (just completed) was devoted chiefly to getting the idea started and to making the physical trail. The project now enters (in 1932) upon its second decade and upon its second stage of development. How to use the 1,400 miles of finished trail to develop a primeval understanding? The answer suggested is to learn how to read—first-hand. To read the earth story contained in the Appalachian Range and the life story contained in the Appalachian Forest.

THE APPALACHIAN RANGE

The Appalachian Range occurs in two generations—the Older and the Newer. The "Older Appalachians" form a chain from the Great Smokies in the South to the White Mountains in the North. This chain is broken in one place only—in the vicinity of the Susquehanna River (Pennsylvania). Southward, it consists of the ancient crystalline Blue Ridge; northward, of similar ancient stock contained in the Hudson Highlands and the various New England ranges. The "Newer Appalachians" or Allegheny Mountains (a sort of magnified ploughed ground) flank the "Older" on the west side. Between the "Older" and the "Newer" Appalachians lies the corridor known as the "Great Valley"—from Chattanooga to Lake Champlain.

East and west of these twin ranges we have a symmetric pattern of plain and plateau (see Fig. 1). East of the Older generation lies the southern Piedmont and the New England Upland (these ancient crystalline areas being separated in the Susquehanna district by the young sandstones of the "Triassic Lowland"). West of the Newer generation lies the middle-aged Allegheny Plateau. East of the Piedmont comes the Atlantic Coastal Plain, newly emerged from the present (eastern) ocean. West of the Allegheny Plateau comes the Interior Lowland—an older coastal plain emerged from an older (western) ocean.

The Appalachian Trail follows the crest of the Older Appalachians—except at the break near the Susquehanna, where it crosses over to the Newer generation (along the Pennsylvania Blue Mountain Range). In so doing the Trail twice crosses the Great Valley.

A cross-section of the structures occurring in the middle Appalachian region (on a line from Ohio to the Virginia shore) is given in Fig. 2. This shows in sharp contrast the two kinds of rock substance: (1) the "Old Land" or ancient underlying hard crystalline material; and (2) the younger overlying softer uncrystallized material (the layers of sandstones and shales). Of the latter structure, the Atlantic Coastal Plain has been so recently emerged from the sea that it is but slightly affected by the elements; but the Allegheny Plateau, which has been exposed much longer, has become thoroughly "dissected." Hence one is flat, while the other is so-called "mountainous."

A panorama of a portion of the Appalachian Range is shown in Fig. 3—a

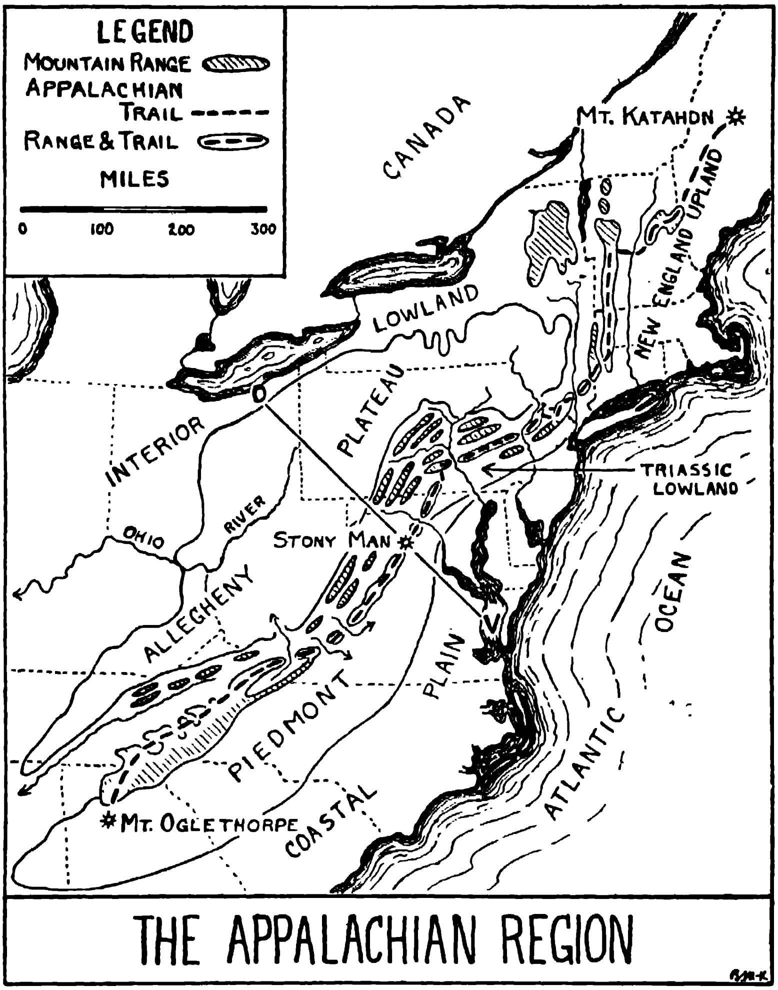


FIG. 1

small portion, indeed, but one sufficient to suggest a telling method of reading landscape. This panorama, embracing the horizon from Mt. Greylock, Massachusetts, to Killington Peak, Vermont, is taken from the convenient vantage point of Mt. Monadnock in New Hampshire. A map is subjoined of the territory within this view, but the panorama itself is the natural "map" going with the "open book" of nature. The *panorama* is one of two main leads toward unravelling the story told directly by the great outdoors.

The other lead is the *cross-section*. A sample is shown in Fig. 4. This cuts from crest to base the east slope of the Blue Ridge of Virginia—from the rocky summit of Stony Man to the lowly valley of Nigger Run; also a section taken from the lower stream (the Rapidan River), and another taken at the stream's mouth (on the ocean margin).

Written large on these great natural tablets (panorama and cross-section) are those records of form and substance and process which together constitute the epic of the ages. From the panorama we see the general features of the landscape; from the cross-section we see what is going on within the landscape.

Let us climb to the summit of Stony Man, and from its panorama make general acquaintance with the primal scenery. Its four elements are there (land, air, water, forest): the hills and dales, the varied clouds, the winding streams, the sylvan coat of summer green (or winter brown).

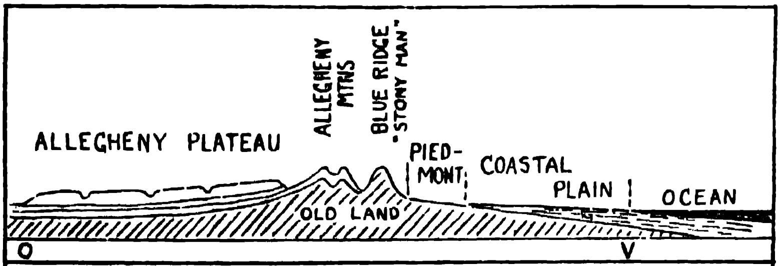
Let us now descend to White Oak Canyon, and from its cross-section make acquaintance with what is going on within the panorama. To do this we follow the canyon's stream—from its source below the crestline to its mouth beneath the ocean. Thereby we trace, from birth to death, the life course of a being which is neither plant nor animal: it is the "being" which we call a river; a mixture of individual and race—its form as rigid as the one, its flow as eternal as the other. We follow this immortal sculptor of the landscape and trace its work through definite stages, and in definite zones of action: (Fig. 4.)

(1) The zone of Weathering—up on the Ridge's rocky brow. Here in the crevices the stream is born, for here collect the rain waters. They freeze and thaw and crack and heave the solid surface.

(2) The zone of Breakage (or "torrential" zone). Down this we pitch headlong through the heart of White Oak Canyon. Come here in the summer drought and look at the cascades falling gently over the high jutting ledges that peer at you from above the hemlock tops: what effect, you ask, can such drippings have upon the landscape? But come again with the early spring freshets and witness yonder cataracts pouring uproariously over those same ledges. This tells another story: the stream in the might of youth chiselling out the mountain; big jagged fragments becoming small rounded boulders; the water dashing them together and hurling them into the gully below.

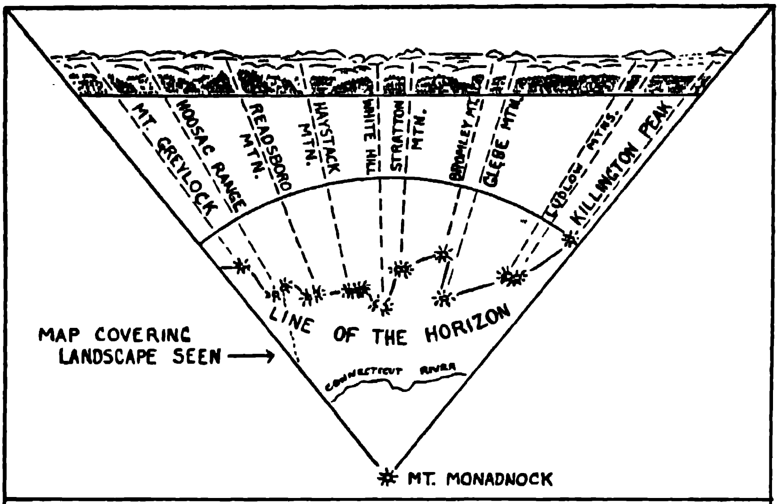
(3) The zone of Grinding. In the less steep lower Canyon where rocks "flow" as well as water. A second brook here joins our first one, making the double stream called "Nigger Run." The small rounded boulders are ground to tiny polished pebbles. These rattle and "flow" on together along with the yet foaming waters, turning gradually to sand, the "flow" whereof begins to clog in the less hurried waters.

(4) The zone of Removal and Deposit. We have jumped a gap and taken up our journey far down the river, halfway to the sea. The stream consists now of several "Nigger Runs" which have come together out of the great wall of the Blue Ridge. Its name is Rapidan River. We have shifted from trail to canoe, and this floats with the current around the big bends and meanders of this cosmic "be-



APPALACHIAN REGION IN CROSS-SECTION
MIDDLE PORTION FROM OHIO (O) TO VIRGINIA SHORE (V)

FIG. 2



A PANORAMA
FROM WHICH TO SEE THE GENERAL FEATURES OF THE LANDSCAPE
THE BERKSHIRE-GREEN MTN. RANGE FROM MT. MONADNOCK, NEW HAMPSHIRE

FIG. 3

ing." But there are two currents—one swift and one slow! The swift one follows the outer edge: it gouges into the bank, tears loose the soil and bears it on in that red soupy flow of mud and water —"half and half." Then on the next swing it becomes the inner current and mopes along the inside edge. Unable thus to carry its burden it drops part of it upon the bottom and so builds up the inside bank. The river (as it were) removes with one hand and deposits with the other; but it removes, in the long run, more than it deposits.

(5) The zone of Ultimate Deposit—where the stream form "dies." We jump another gap and end our journey on the margin of the sea. The stream, too, ends its journey; its waters mingle with the great eternal of the ocean, but its soils drop lifeless on the ocean floor to build their little quota of that long "shelf" that reaches around the continent.

Thus we see the river acts as sculptor of the landscape—a cutter and a builder too, but more a cutter than a builder. "Statistics" show that the Potomac River system (not the Rapidan) cuts (or scrapes) each year from the area drained about 1,358,000 tons of solid earth suspended, plus 1,787,000 tons of material dissolved. This material amounts to a layer one inch thick removed from the drainage area every 870 years. This process of scraping is called *erosion.* Thereby is the land removed from places above to places below the surface of the ocean.

In tracing thus upon our cross-section the primal mode of landscape sculpture we get acquainted with the main things going on within the landscape's panorama (except within the forest). We carve an opening into those imposing facts which (as stated) constitute the epic of the ages—the form and substance of the country seen, and the process whereby it is molded. Each map and sketch and photograph, when made with care and due selection, adds to our total picture of the form; every specimen of rock and soil, with accurate note of its location, reveals a bit of knowledge of the substance; any systematic record of

rainfall and stream flow, any map or description of river turn or waterfall, builds up our visualization of the process. In uniting thus the acts of artist, collector and observer we epitomize the Appalachian landscape and in our minds create the setting for the complete primeval story.

Here then is one "pursuit" in which we can engage in order to become "acquainted with" the scenery. It is something which we can carry as far as we like—on the Blue Ridge of Virginia or the Green Mountains of the North, or the Great Smokies of the South, or anywhere else on the Appalachian Trail.

But other pursuits await us if we would truly read the complete primeval story of the Appalachian scenery and range. It is not enough to know this range merely as it exists to-day. Whence came it—and how? What of its genesis?

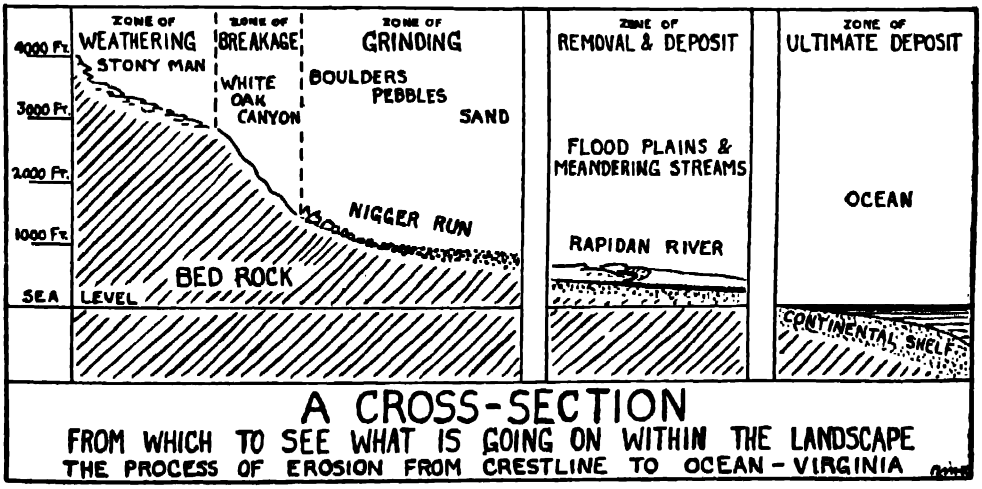
GENESIS OF THE RANGE

Let us take a second trip to Stony Man and look again upon its panorama. The surrounding ridges and lowlands mean more to us since our trip down the cross-section and our personal discovery of the great process of erosion. The whole country, as stated, is being slowly cut down and shovelled out to sea by thousands of hydraulic dredges—the rivers. Given time the whole country—if nothing else happened—would be cut down to the level of the sea (so-called "base level"). The soft lands are cut faster than the hard: hence we have the low broad plains of soft and extensive limestones and the high narrow ridges of hard and limited crystallines. Both are cut down slowly but the ridges more slowly than the plains.

Cut down from where?

Something keeps shoving the continents up high above the sea. Else long ago erosion would have ground them down to base level; our planet's surface then would be an endless sheet of ocean and its life limited to fish and lower beings. So something else *has* happened—and keeps on happening. This something else is another process—the counter process to erosion. It occurs in various forms:—volcanic upheavals, lava flows, general uprisings of the land (accompanied by earthquakes). Its name is *uplift.* Its cause is "subterranean"—the working and squirming of the superheated substance beneath the cool exposed earth "crust" on which we live.

This crust originally consisted of cooled-off molten substance—of "igne-



A CROSS-SECTION
FROM WHICH TO SEE WHAT IS GOING ON WITHIN THE LANDSCAPE
THE PROCESS OF EROSION FROM CRESTLINE TO OCEAN - VIRGINIA

FIG. 4

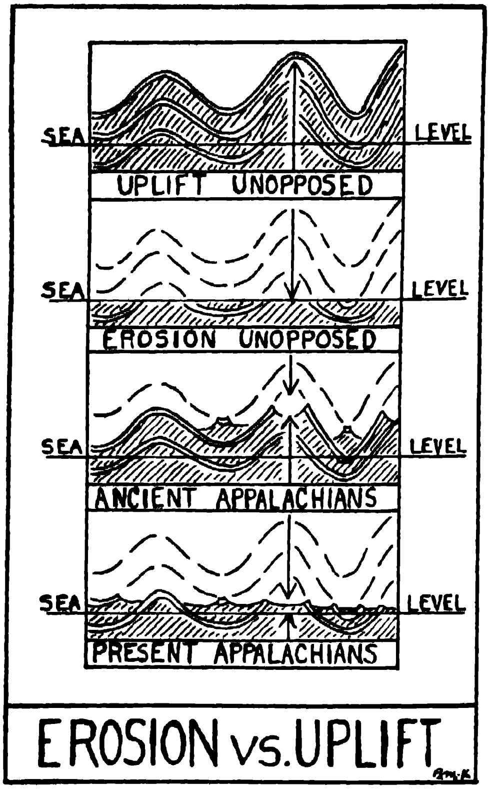


FIG. 5

ous'' rocks, the class to which granite and lava belong. These igneous rocks formed the original stuff, stock and ancestry of all the continents. As soon as they stuck their heads above the ocean, erosion attacked them, broke them into fragments, ground them into powdered form, and spread them as freshly made material out upon the ocean floor (as we have seen). This material, hardening into layers (or ''strata''), became sandstones and other kinds of so-called ''stratified'' or ''sedimentary'' rocks. Hence this new kind of rock was deliberately made and manufactured out of the old, original, igneous rock. We might call them by two names —the primal or fire-made rock, and the ''manufactured'' or water-made rock.

These layers of stratified or manufactured rock (and re-manufactured rock) have come to form a substantial portion of the earth's crust. As the earth contracts (with its cooling and shrinking) the crust wrinkles up in places (just like the skin on a drying apple).

The Appalachian region is one of those places. Here (late in the Paleozoic Era) several great layers of manufactured rock (some old, hard and crystallized, some younger, softer and even-textured) were lifted and wrinkled into enormous folds. By this process of uplift the topmost layer—if nothing else had happened—would have folded into one or more arches which would have reached possibly 30,000 feet above the sea. But something else of course *did* happen, namely erosion, and the tops of the arches were kept down to less than half of the height which uplift unmolested would have achieved. The Appalachian Range of Paleozoic time might have been Himalayan in stature; but erosion kept it down to Alpine altitudes, and since then has reduced it to the modest Virginian heights such as the top of Stony Man, 4,010 feet above the sea. This balance of forces (erosion *vs.* uplift) is illustrated in Fig. 5, for the several conditions which have been described.

So the tops of the folds were cut off by erosion and placed back on the sea floor whence they came. Here their substance was remanufactured into a second edition of sedimentary sheets and in the course of ages was raised again above the sea by uplift—not in folds this time but as a level or gently sloping plain along the middle Atlantic coast (the ''Coastal Plain''). See Figs. 1 and 2. In time comparatively short erosion *via* its meandering rivers (like the Rapidan) will scrape this coastal plain away and place the substance once more on the sea floor—there to harden to a ''third edition.''

Thus moves the land up and down across sea-level—uplift pushing it up in solid masses, erosion washing it down in severed particles; thus land itself moves in a series of cycles from sea back to the sea—even as the waters (in their infinitely shorter cycles). And so as the great Huxley says:

> The land is therefore subject to a kind of circulation similar to that . . . in the case of water. The water, it will be remembered, passed from the river to the ocean, and back again from the ocean to the river in the form of rain. In like manner, the solid land is constantly being carried, piece by piece, into the sea. Here most of it is spread out upon the ocean floor, forming deposits which will some day be raised as dry land; and will then be once more attacked by the water, as soon as it rises above sea level. The solid earth is, therefore, subject to a cycle of changes not less complete than that exhibited by the circulation of the waters.[1]

Such, in brief, is the colossal earth story which has been "read" by Huxley and other great readers from all portions of our planet during the past revealing century. From panorama and cross-section, and their fascinating first-hand pages, we "illiterates," too, can learn to read this story. The lead in this would be to find what stage in the land-circulating cycle we now occupy: specifically—what our landscape has looked like from time to time since the cycle began. What manner of "motion picture" may we vision of these shifting cosmic scenes?

Here is another "pursuit" which can be carried on from the Blue Ridge, or Green Mountains, or the Great Smokies, or from anywhere along the Trail:—the reading of the genesis of the Appalachian range.

And next—what about the Appalachian forest?

THE APPALACHIAN FOREST

We make a third trip to Stony Man—this time to take special notice of that forest at which we took a fleeting glance in our first ascent. Let us first take an outside look at this forest—from the panorama. Then we shall take an inside look—from the cross-section.

In order first to get an *outside* knowledge of the Appalachian forest, and of the distribution of its various types, we must map the panorama not only from Stony Man but from various other points along the Appalachian crestline. As a background for this we shall now in imagination (and with the aid of Fig. 6) map this mountain forest, not only in several places but in several periods. We shall follow through a forest "cycle" (for the forest has its cycles as well as the waters and the land). This one is climatic: it is a little cosmic turnover which has "just recently" occurred, from temperate forest to temperate forest, before and after the last invasion of the ice sheet. This invasion was at its height about 40,000 years ago. This is "recent"—absurdly recent—as seen upon the cosmic time table. Translating to the American history time table and placing the latterly Paleozoic Era at the "War of 1812" would place the middle of the glacial period about six "days" ago.

Our climatic cycle of the Appalachian forest goes back about ten and one half of these "days," or about 70,000 actual years. Since then the Appalachian range itself (save for the scars and mouldings of the ice sheet) has been changed but insignificantly (either by erosion or uplift). At that time our well known temperate hardwood forest (of oaks, maples, birches, and the others) covered the range from south to north (interrupted then as now by lowland evergreens like pine and hemlock).

Fig. 6 shows three climatic forest forms. These exist to-day in three types of North American vegetation: (1) the temperate hardwood forest of the Southern and Central United States; (2) the subarctic spruce forest which crosses Canada south of Hudson Bay; (3) the

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[1] "Physiography," by T. H. Huxley, Chapter XIII, pp. 215–216.

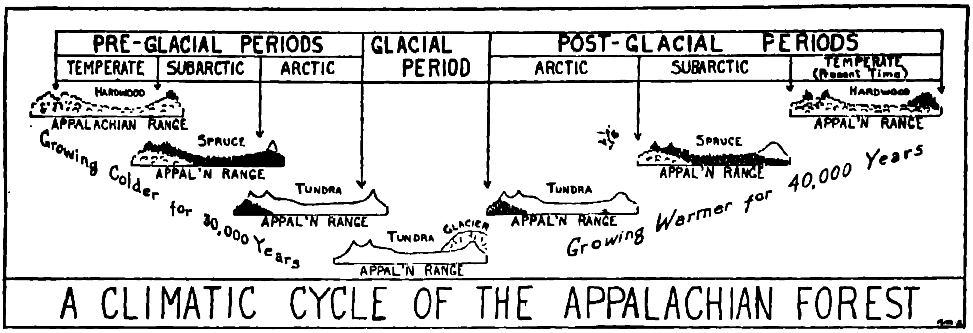


FIG. 6

arctic tundra (of willows, moss and lichen) which occupies the continent northward from James Bay. These three types of forest occupied successively the body of the Appalachian range during the three pre-glacial periods while the ice sheet was approaching from the north; in each period the lower slopes of the southern mountains were covered by the type belonging to the period next warmer, while the upper slopes of the northern mountains were clothed by the type belonging to the period next colder. The glacier at its culmination got about as far south as the Hudson Highlands and the Delaware Water Gap. During the three post-glacial periods, while the ice sheet was retreating, the range was occupied by the three types of forest in reverse order—arctic, subarctic, and temperate.

To-day the temperate hardwood forest is back again, but King Spruce reigns in large portions of the north (when unmolested by mankind). And his realms are also in the south (even as far as the Great Smokies). They occur along the crests and summits in a series of "boreal islands," while the boreal "King" himself, defiant of the encroaching hardwoods, stands forth the rude rugged remnant of subarctic times and reminds us that the cycle is not yet quite complete.

The cycle described is an example of what botanists and ecologists call a "climatic forest succession." There are several other kinds of forest succession—such as the biotic, the physiographic and the anthropic. Any of these might well be explored—on panorama and cross-section—as an aid to becoming acquainted with the Appalachian scenery.

In order now to get an *inside* knowledge of the Appalachian forest—of its species and their mutual relations—we shall again follow the trail down the Ridge's side. As in reading the range, so in reading the forest, cross-section follows panorama. We may retrace our steps through White Oak Canyon to the Rapidan, in quest, this time, not of what is going on within the land, but of what is going on within the forest. What is the make-up of the forest "population"? How does it cooperate to make a living?

"Who's Who" in the Appalachian forest shows the tree family to be the aristocracy. There is white oak himself with the numerous brothers of his genus; there is the sublime tulip; and the ashes, the hickories, the late and mourned chestnut; also the pine and his brother conifers—and about a hundred others. There are the shad-bush and the dogwood and the hundred shrubs. There are the trailing arbutus in secluded dells and a hundred other wild flowers. There are the gorgeous ferns, the mosses on the rocks below, the lichens on the cliffs above, and a world of fungi in the fallen tree. Down in the pools are green algae that we dispose of as mere "slime."

And then there is the whole animal kingdom—the other half of the forest population. The clam perhaps is one of the lowliest animal citizens. Of insects the castes are legion. There are trout in the brook (let us hope). There are frogs and salamanders, turtles and moccasins. Ducks light on the waters, songsters fill the trees, and the hawk soars up above. Muskrats follow the streams, while squirrels, foxes, wild cats and deer roam the woods generally. King Primate only is absent (except in clothing).

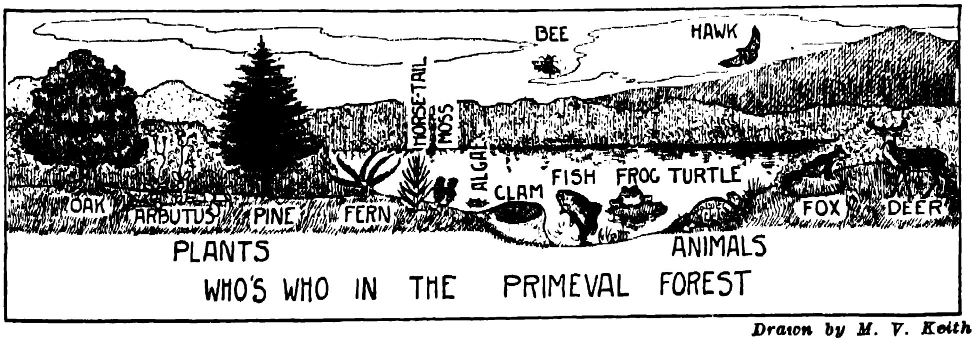
Such is "Who's Who" in the primeval forest. A select list from among them is shown in Fig. 7: plants on the left and animals on the right; the lower orders in the center and the higher orders on each side.

How do they all make a living? Just as men do—by cooperation and division of labor. But (as with men) cooperation bred on the tough experience of competition. The primeval forest is a balanced and independent society. It is still a warring society. It is not an Utopia, it is merely a civilization. Most of its folks live in cities—the ants and bees and hornets. Some live on farms—the lichens that first extract the food from Mother Earth. Others—like foxes —dwell part-time in subways; frogs occupy the waterfront; while songsters make their living in the skyscrapers. Each one is consumer and producer; some "produce" by preying on others; everybody has a job; the less work the less food; resources in plenty and no markets; no middlemen, no salesmen. In unravelling the forest civilization we reveal the contrasts of our own.

Here is one more pursuit for getting acquainted with Appalachian scenery and absorbing its primeval influence—to picture accurately the forest both from outside and from in. From the crestline panorama to trace its outer aspects in the cosmic cycle before and since the glacial period; from cross-section to trace its inner constituents and workings.

The primeval forest is an epitome of all land life except the human. It is worthy of a tracing both comprehensive and comprehensible. In this the collector of specimens (plant and animal) might well play the constructive part, remembering that the value of the specimen lies not at all in quantity but wholly in selection. The collector alone could, with right imagination, reveal to the average amateur naturalist a conception of total life such as he never had before.

But the forest as it is in the cosmic "present" (within the "days" since glacial times) is a small part only of the whole. It forms the end of a story but no evident portion of the middle or beginning. To the pursuit therefore of picturing the forest as at "present" let us add that of visioning its genesis.



Drawn by M. V. Keith

FIG. 7

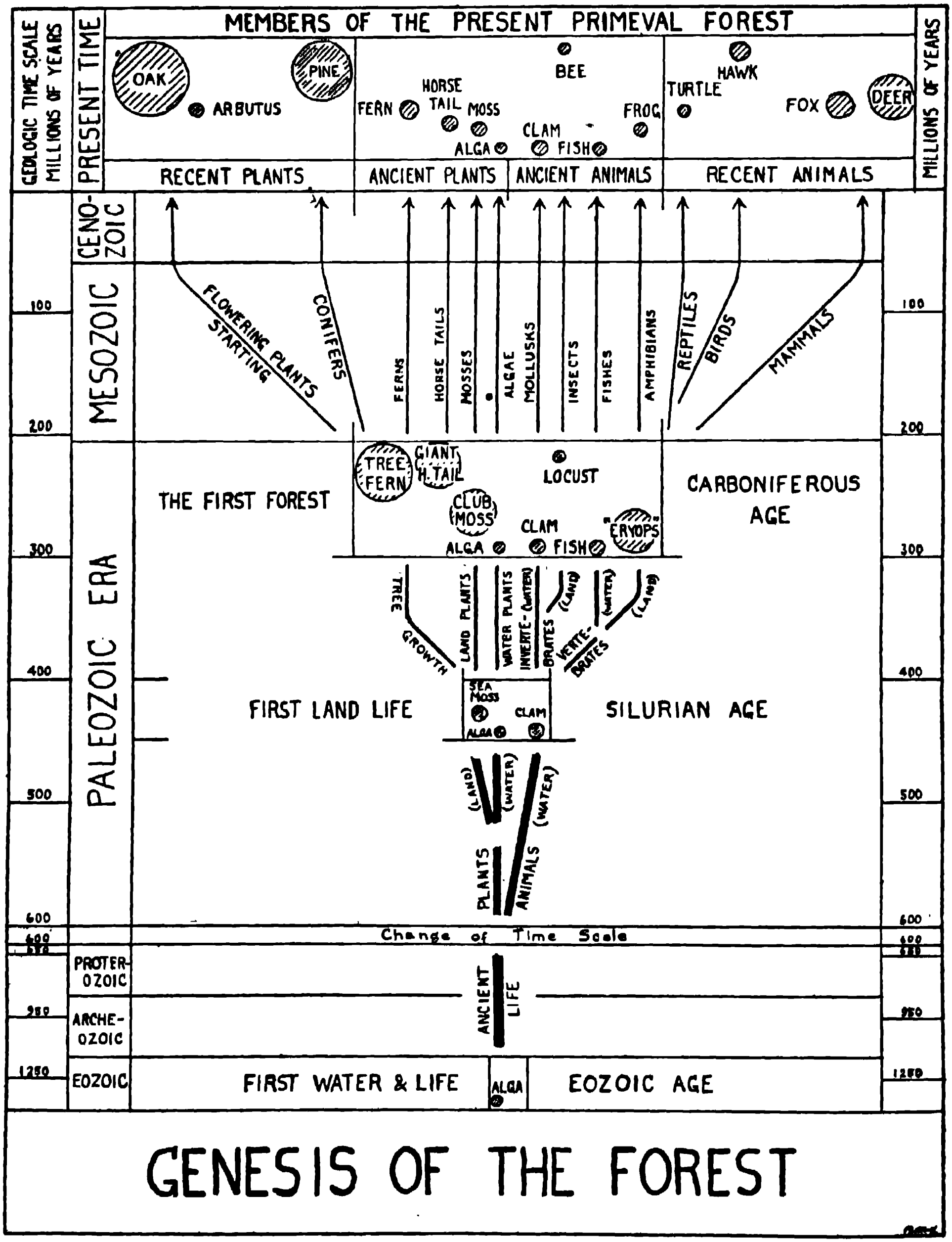

GEOLOGIC TIME SCALE MILLIONS OF YEARS
PRESENT TIME
MEMBERS OF THE PRESENT PRIMEVAL FOREST
MILLIONS OF YEARS
OAK
PINE
ARBUTUS
FERN
HORSE TAIL
MOSS
ALGA
BEE
CLAM
FISH
FROG
TURTLE
HAWK
FOX
DEER
RECENT PLANTS
ANCIENT PLANTS
ANCIENT ANIMALS
RECENT ANIMALS
CENOZOIC
MESOZOIC
FLOWERING PLANTS STARTING
CONIFERS
FERNS
HORSE TAILS
MOSSES
ALGAE
MOLLUSKS
INSECTS
FISHES
AMPHIBIANS
REPTILES
BIRDS
MAMMALS
100
200
300
400
500
600
THE FIRST FOREST
TREE FERN
GIANT H. TAIL
CLUB MOSS
LOCUST
CLAM
ALGA
FISH
ERYOPS
CARBONIFEROUS AGE
PALEOZOIC ERA
TREE GROWTH
LAND PLANTS
WATER PLANTS
INVERTE- (WATER) BRATES (LAND)
VERTE- BRATES (WATER) (LAND)
FIRST LAND LIFE
SEA MOSS
CLAM
ALGA
SILURIAN AGE
(LAND)
(WATER)
(WATER)
PLANTS
ANIMALS
Change of Time Scale
600
650
PROTEROZOIC
950
ARCHEOZOIC
ANCIENT LIFE
1250
EOZOIC
FIRST WATER & LIFE
ALGA
EOZOIC AGE
GENESIS OF THE FOREST

FIG. 8

GENESIS OF THE FOREST

We might make a fourth trip to Stony Man, but it would aid us little in visioning the genesis of the Appalachian forest. In this the intimate look-ins on the cross-section are more useful than the sweeping look-offs on the panorama. But first we shall stay at home and survey in imagination the results of a hundred years of intensive research, made since Darwin's day, based on the vague gropings of the centuries since Aristotle. A notion of this survey is shown in Fig. 8.

We have had a look at the "present day" primeval forest—its organization and its various plant and animal members. We might get our collectors to place these members in a row—plant to the left, animals to the right (a sample species for each of the major groups) thus:

Plants (from high to low)—oak, pine, fern, moss, alga (or "slime").

Animals—deer, hawk, turtle, frog, fish, locust, clam.

These members, already shown in Fig. 7, are indicated also at the top of Fig. 8.

A "Who's Who" for the carboniferous forest may now be made by naming the families or groups from which the above species have directly descended:

The carboniferous plants (from high to low): The tree fern, ancestor of the recent low-growing variety; the horsetail and the clubmoss, ancestors of the recent diminutive horsetails and club mosses. These grew as tall as our recent trees. Finally the algae, or green slime on the waters: this type has changed almost none during all geologic time—the same "yesterday, to-day, and forever."

One plant member of the carboniferous forest was of higher order even than the tree fern. This was the giant cycad. But it was a "great uncle" rather than the grandfather of the present Appalachian trees, the conifers being the nearest of kin.

The carboniferous animals: Amphibian, represented by a crocodile-like creature called "Eryops," an ancestor of present animals living in and out of the water—such as frog and salamander. Fish—of various kinds not unlike our moderns. Insect—of numerous kinds, among which are the first cockroaches and locusts. Mollusk, of which the clam is typical.

These carboniferous members (plant and animal) are also shown in Fig. 8.

The luxuriant carboniferous forest which contained these families and grew our anthracite has long gone into fame. We need not describe it in this article. But how can we picture it outdoors? We can not do it from Stony Man, nor in White Oak Canyon. We might do it best perhaps in the Great Dismal Swamp in coastal Virginia; but let us take some swampy bottom at the foot of one of the southern Appalachian ridges. Visualize here a moving picture and run it backward to see what would happen if we could travel back in time: The oak would disappear; the pine would come to look something like its "Uncle Cycad"; the ferns would grow bigger and bigger until they were as tall as our pines—and much more sprawling; the deer, the fox, the birds, the reptiles all would disappear; the amphibians would remain—and the salamander would grow big like an alligator and turn into "Eryops"; fish, locusts, and clams would remain much as they are. And the green slime would stay put on the stagnant waters.

In some such way we might in time teach ourselves to read—first-hand—on the out-of-doors horizon—the genesis of the Appalachian forest. In this we would have to borrow from the research of the centuries. Our amateur collectors might arrange for us a rough genealogy of the forest species by graphic restorations of the departed ancestors, and in this way bring back the forest as it looked and lived in the stages between the carboniferous and now.

But to get the total story we should

have to look behind the carboniferous—which dates back only a quarter of the span that made the forest—and the living world. Our next stop might be in the Silurian Age (almost halfway back). The landscape of that day we should find a desolate thing: mountains there are and clouds and rains and streams and weathered soil, but a lifeless continent except along the shore; here we find the seamoss—the start of life upon the land, a plant life only, the crude low ancestry of moss and fern; but on the tideland, the tiny thread where continent and ocean overlap, we find the pioneers of landward animals in the like of snail and worm; all else belongs to water—sponge, squid, starfish, clam—and green slime the eternal in the stagnant pools.

Then go back twice as far again—to the Eozoic Age: Land only, and "igneous," no "manufactured" kind; no ocean, only a film of wetness; no atmosphere except a heavy carbonated film with thick winds and drippings as of rain; the planet's surface lately molten and just cool enough to let steam liquefy in spots. And with moisture—vitality: bacteria somehow come—and the green slime.

One more pursuit to get acquainted with the scenery: to trace the genesis of primeval life—and know that when the vital spark lights up in you it belongs not to you but to the ages.

To Read the Primeval

We have had a look at the Appalachian range and the forest on its slopes. We have surveyed them at long sight, and also in close view—in panorama and in cross-section. We have looked out and looked in. We may also look up—and thereby scrape some crude acquaintance with the stars, and with our nearby cosmic neighbors, the sun and moon and planets. We have obtained some notion perhaps of how to go about the pursuit of learning how to read, from the Appalachian Trail, to open book of primeval nature.

It is just a matter of putting this and that together. Let us continue to collect our specimens—of rock and mineral; of leaf and bud and fern and flower; of bird and skin and snake and bug: but let us weld them into some comprehensive whole through the disclosing medium of imagination. In this way only can we read the story that lies about us; thus only may we reveal (as would the radio) the harmonies and secrets which make our unseen world. It is a method as old as Aristotle. Thereby have we become endowed with the colossal and overwhelming tale of nature's simple processes found (and lost alas) in the myriad printed scientific treatises that fill our libraries. To the single specialist a single story comes to be known by heart—with or without its full appreciation. To the rest of us—we average numskulls who pace the earth—comes in any landscape a cataclysm of age-wrought deeds which so far transcends our understanding that our appreciation and the joys thereof are whittled down to grunts and exclamations. The young collector with his bugs and minerals secures the elements of nature's puzzle picture—and learns thereby his separate "ABC's"; but not until he fits them each in place does he learn to read the "open book" itself.

To learn to read—first-hand—on the horizon and along the stream—the big outlines of the primeval drama; to take specifically the Appalachian country as the common school and playground; to weave together the threads containing the total story of this country (even as already we have woven the separate sections of our total footpath): this appears to be the logical second stage for the second decade of our enterprise. A "pursuit" such as this to become acquainted with our scenery should be the next step in developing the Appalachian Trail.

VARIABLE STARS

By Dr. L. V. ROBINSON

ASTRONOMER, HARVARD COLLEGE OBSERVATORY

THE layman who has casually observed that the Big Dipper is always a dipper regardless of its position in the sky may also have noticed that all the stars appear to keep the same positions relative to one another. In general, the only exceptions are the planets. The layman, from somewhat hurried glances, may also be inclined to think that all the stars remain unchanged in brightness. If he could observe the stars a few thousand years hence, however, he would be convinced that "the stars do move," and a few days or weeks of continuous observation would also show changes in brightness of many of the brighter stars. The sun shares the motions of the other stars; in fact, it is dragging our little earth through space with a velocity of twelve miles per second relative to the other stars; but we move at a very slow rate compared with some of the suns, which are so far away in space that we call them stars.

The reason why the stars do not appear to move is that they are so exceedingly far away. Even the nearest is 275,000 times as far away as the sun is from us (that is, 275,000 × 92,900,000 miles), and light from this star does not reach us until it has been on its journey four and one third years. Light from the sun reaches us after a short journey of only eight minutes. By way of contrast, it is said that the sensation of a burn travels so slowly, relative to the speed of light, that an infant with an arm long enough to reach the sun would live his allotted time of three score and ten years and die in ripe old age before learning that his fingers had been burned.

But what of the brightness of all these far-away suns? By actually measuring their distances, astronomers can compare the brightness of each one with that of the sun. The intrinsically brightest star now known is one that is apparently associated with the great Magellanic Clouds of the southern sky. This star, called S Doradus, is not only important because of the fact that at times it is half a million times as bright as our sun, but also because it represents one class of stars known as "variables," on account of their variation in brightness. Among the variables, S Doradus is probably related to the sub-class which the astronomer calls novae.

Within the earliest records of man the first star observed to vary in brightness was indeed a nova in the constellation Scorpius and was discovered by the Greek astronomer, Hipparchus, 134 years before Christ. This star, which appeared very suddenly as a dazzling bright object where one had not before been seen, aroused the curiosity of Hipparchus and undoubtedly prompted him to compile the first catalogue of star positions, by reference to which the appearance of any new star, or the disappearance of any of those which he had already observed and catalogued, could be established.

The outstanding peculiarity of novae is that they manifest a sudden outburst in brightness and then gradually fade away, becoming invisible to the unaided eye after a few weeks. The second known star of this kind, a nova in Cassiopeia, was observed first by Tycho Brahe, a Danish astronomer, in 1572. When Tycho first saw it, this star was among the very brightest in the sky; within a few days it grew still brighter so that it could be seen even in daytime without the use of a telescope. When the planet Venus is at its brightest, it is possible to observe it in the daytime, provided we know in what part of the sky to look, but Tycho's star is said to have been even brighter, notwithstanding the fact that Venus approaches us as closely as 26,000,000 miles, whereas most novae are probably hundreds of millions times as distant.

In recent years a more careful watch has been kept over the stars; in fact at Harvard, the whole sky is photographed many times in the course of a year's work. Also more people know the constellations and recognize very quickly the presence of any new bright star where previously none had appeared. As a result, known examples of novae have increased fairly rapidly in recent years. The brightest of the recent ones appeared in 1918 in the constellation of Aquila. In less than a week the normal brightness of this star increased nearly 70,000 times, and on June eighth it was exceeded in brightness by only one other star, Sirius.

With the instruments now at the astronomer's disposal, he is able to detect the presence of gases rushing out from these stars with velocities as high as 1,200 miles per second. We are led to conclude, therefore, that the great increase in brightness of these stars is due to an increase in diameter caused by some kind of explosion. The frequency of these explosions suggests to us that possibly similar disturbances occur within every star, at least once in its lifetime. If so, what warning are we to have of the approach of an explosion of the sun? The sun is only a star among the thirty thousand million others which astronomers believe are in our Milky Way system. Why then should it be the exception to the other stars? What if it should explode? We frequently see spots on the sun large enough to hold our little earth; we might therefore be justified in concluding that in a solar conflagration, similar to that which apparently takes place in a nova, the earth would disappear almost instantaneously.

As a representative of a second type of variable there is none better than Mira, the Wonderful, a star in the constellation of Cetus, which changes continuously in brightness, reaching a maximum and minimum periodically. Mira was first seen by the Dutch astronomer, Fabricius, in 1596; it appeared as a star of moderate brightness where one had not previously been seen. In a few weeks it had faded away and it was therefore thought to be a nova, until the year 1638 when it was seen again by another Dutch astronomer, Holwarda, who observed that it appeared and disappeared within a period of about eleven months. To the telescopic observer this star does not actually disappear, but when it is faintest it gives only about one per cent. of the visual light which it gives when it is brightest. Since the time of Fabricius and Holwarda, the number of recognized stars of this type has increased, especially during the last few years, until now our catalogues contain about two thousand other examples.

All of the stars of this type are more or less red and appear to be among the coolest stars in the sky. In their outer layers at least, they apparently vary in temperature and in color as well as in luminosity, but the highest temperature exhibited by a variable of this type never exceeds that of a very hot furnace, while many of the blue stars show temperatures ten times as high. Among the giant stars, in general, low temperatures and large diameters are very closely correlated and are thought to be characteristic of the earliest stages of a star's development. The enormous size of Mira is illustrative, probably, of all long-period variable stars. If the sun were placed at the center, inside the body of Mira, and the distance (92,900,000 miles) between the sun and its companion the earth were unchanged, the earth would be several million miles below the surface of the star. Not only the earth, but Mars, which is 50 per cent. farther away from the sun than the earth, would be beneath the surface of this giant star.

At the level, which we call the surface of Mira, the constituent gases are much rarer than those composing the atmosphere of the earth, fifty miles above its surface; in fact they are in a rarer condition than can be duplicated by exhausting the air of a vessel with the best air-pump yet constructed. The rarity of the gases at the surface of this star is due to the smallness of the gravitational pull which varies inversely as the square of the diameter. A man weighing 200 pounds on the earth would weigh less than four ounces at the surface of Mira, were it possible to weigh him with spring balances in each case. On the small dwarf star circling about Sirius, by way of further contrast, this man weighed by the same method would weigh no less than 3,000 tons, whereas on our sun he would weigh only 5,500 pounds, or somewhat less than *three* tons!

In many ways the class of variable stars to which Mira belongs, ordinarily called long-period variables, is closely related to another type known to astronomers as Cepheid variables. The earliest observed type of this class is Delta Cephei, discovered by Goodricke in 1784. These stars are not so red as the long-period variables, and their periods of variation extend from a few hours to about seventy days, whereas the periods of long-period variables range from about 100 days to about two years. Furthermore, the range of variation in brightness is, in general, much less in the case of Cepheids than in some Mira-type stars where the brightness at maximum is 50,000 times that at minimum. Astronomers believe, however, that Cepheids are related to long-period variables because a correlation between redness and period, which has been noted among Cepheids, can also be extended to the long-period variables. The Cepheid variables and those of long-period are generally believed to be pulsating—that is, both classes may owe their changes in brightness partly or wholly to periodic expansions and contractions of the gases composing them. There are some astronomers, however, who believe that the variations in luminosity of the Cepheids are due to rotation and to their peculiar shapes. It is claimed that they are pear-shaped and eventually break up into two stars. Each theory has its objections, and much more work remains to be done before the matter can be considered as settled. (Fig. 1.)

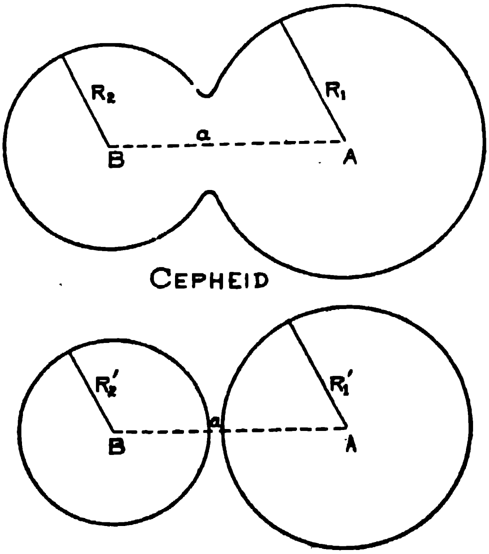


FIG. 1. ACCORDING TO THE JEANS THEORY,

THE TRANSITION FROM THE CEPHEID STAGE MAY BE THE RESULT OF CONTRACTION. THUS R_1 AND R_2 DECREASE TO R'_1 AND R'_2, RESPECTIVELY. IN THE FIRST CASE THE SUM OF R_1 AND R_2 IS GREATER THAN THE DISTANCE FROM A TO B, AND IN THE SECOND IT IS LESS.

The question, "What are Cepheid variables?" is hardly more interesting than the question, "What are they good for, astronomically?" In fact, solving the latter question has served astronomical advancement to a far greater extent probably than any other research which has been pursued in many years. It happens that in certain star clouds and clusters many Cepheid variables are found. In studying the variables in the Magellanic Clouds, Miss Leavitt, at Harvard, discovered that a relation exists between the periods of variation and the apparent brightness of these stars: the longer the period, the brighter is the star—the so-called period-luminosity relation. Since all the stars in the Magellanic Clouds are at very nearly the same distance from the earth, it can also be demonstrated that a relation exists between period and *actual* or *absolute* brightness. In other words, if we know the actual brightness of one Cepheid variable, then we can compute the distance of any other star of this type, once its period and apparent brightness are known. This is equivalent to saying that we must know the "zero point" of the period-luminosity relation in order to use it effectively. The zero point is determined from the apparent motions of the stars, since those nearest to us appear to move the fastest; hence the distance and therefore the brightness of an average star may be known. (Fig. 2.)

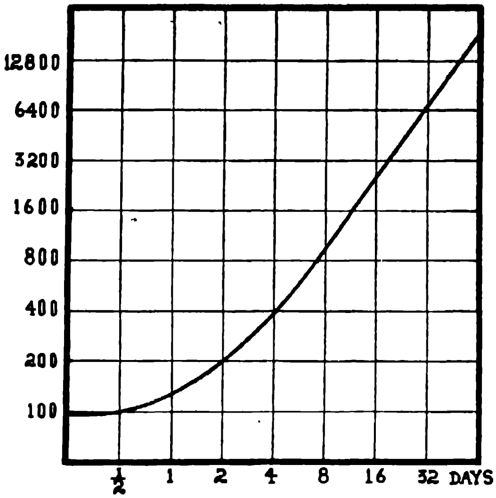


FIG. 2. THE PERIOD–LUMINOSITY RELATION.

HORIZONTAL AXIS IS PERIOD IN DAYS, AND VERTICAL AXIS IS INTRINSIC LUMINOSITY IN TERMS OF SUN'S BRIGHTNESS. THE ZERO POINT IS FIXED WHEN IT IS KNOWN, FOR EXAMPLE, THAT THE AVERAGE CEPHEID WITH A PERIOD OF TWO DAYS IS 200 TIMES AS BRIGHT AS THE SUN.

The period-luminosity relation proved to be the key that unlocked one of the secrets of the universe. The key was immediately seized by a young astronomer at Mount Wilson Observatory, and soon we knew the distances of all the far-away clouds in which the telescope revealed the presence of Cepheid variables whose periods could be determined. This young astronomer was Dr. Harlow Shapley, the present Director of Harvard College Observatory.

The enormous brightness of Cepheids favors their use as yardsticks in measuring the size of the universe. The faintest of these stars, the so-called cluster-type Cepheids, are intrinsically more than a hundred times as bright as our sun; consequently one of these stars can be seen when it is more than ten times as far away as a star of the brightness of our sun. The brightest representatives of the Cepheid class, which are about 10,000 times the brightness of the sun, can be seen at vastly greater distances. The huge 100-inch Mount Wilson telescope shows stars which give less than one millionth the amount of light of the faintest stars visible to the unaided eye, and consequently with it one sees stars over a thousand times more distant. In fact, Cepheids on the outskirts of our universe and among the great star clouds of the Milky Way system are visible in the Mount Wilson telescope. The farthest cluster of stars measured by Shapley was so far away that light received from the members was over 200,000 years old; or, the cluster is said to be 200,000 light years distant. In the opposite direction, clusters were observed at distances of the order of 100,000 light years. For the first time in the history of astronomy investigators could say definitely that the universe had been sounded, and that its diameter was so large that 300,000 years were required for light to traverse it. Yet only a short time later, Hubble, at Mount Wilson, began to count variable stars, such as Cepheids and novae, by the dozens in the Andromeda nebula, identifying it as a great collection of stars, sometimes called an "Island Universe." He was able to measure distances more than three times as large as those previously determined. From this great collection of stars, which to the unaided eye appears as a hazy spot in the sky, nearly one million years is required for light to reach us. Some idea of the distance of this far-away cloud of stars can be gained when it is recalled that light from the sun reaches us in only eight minutes. (Fig. 3.)

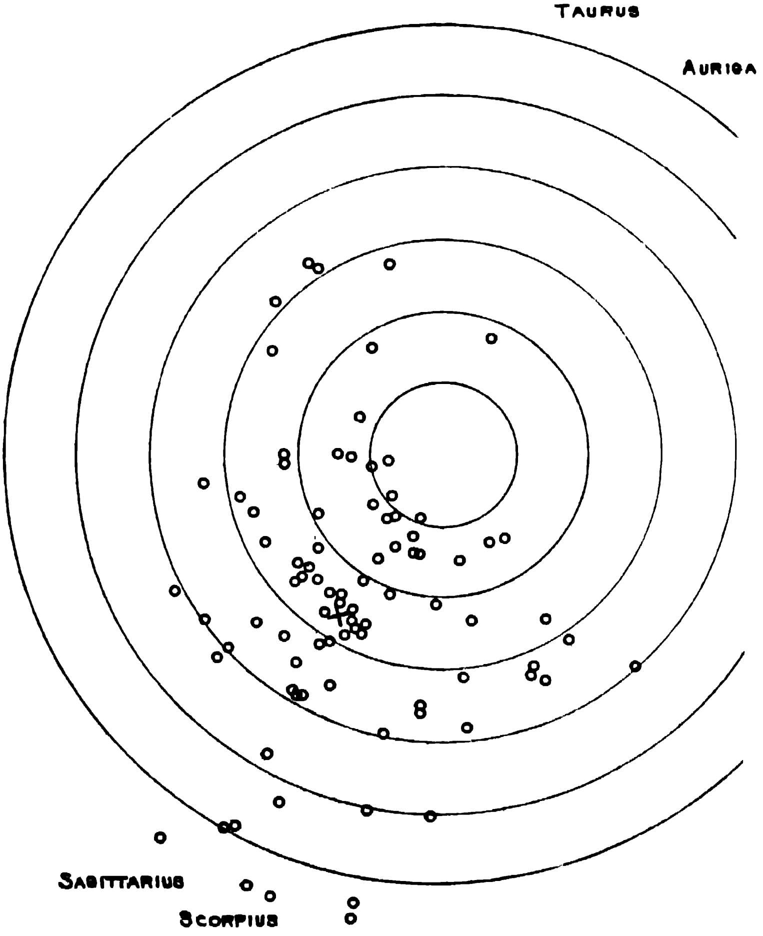


FIG. 3. DISTRIBUTION OF GLOBULAR CLUSTERS.

Plane of paper is plane of Milky Way; large concentric circles represent distances from sun (at center of diagram), the unit being 25,000 light-years; the center of the Milky Way system is represented by a cross. Small circles represent globular clusters; farthest cluster is too far away to appear on the diagram.

The variable stars hitherto discussed are all intrinsically variable and in this way differ from the class of objects represented by Algol and Beta Lyrae. Algol, or Beta Persei, may have been recognized as a variable by the Arabs, since it was called by them *al Ghul,* or the demon, possibly on account of its apparent capricious drops in luminosity. The first historical evidence of its variability, however, seems to rest with Montanari, who noticed its variability in 1669, without attempting any careful study of the star. It was observed again in 1782 by a young Englishman, John Goodricke, a deaf mute, who not only determined its period of variation but also correctly suggested the cause. Beta Lyrae was discovered two years later by Pigot, a friend of Goodricke. Each of the two systems just mentioned owes its variability to periodic eclipses by the component star. In the case of Algol, one of the components is faint relative to the other, which is called the primary, whereas in the case of Beta Lyrae both components are approximately of the same brightness and relatively much closer together than the components of Algol. In fact, for many systems of the Beta Lyrae type, the components, which are generally of the same brightness, are very nearly in actual contact. The range of periods of eclipsing stars, including those of the Algol and Beta Lyrae types, agrees very closely with the range of periods of Cepheids. The amount of change in brightness is also about equal to that of Cepheids. For eclipsing stars, the amount of change depends upon the relative brightness of the two components of the system and upon the orientation of the plane in which they revolve to the line of sight.

It is clear that eclipsing stars constitute a very special selection among double stars: they are those systems where one star passes in front of the other and cuts off a part or all of its light, in much the same way that the moon cuts off the light of the sun when a solar eclipse occurs. They constitute only a part of those close doubles which to the unaided eye or in the telescope appear as single stars. There are other systems whose components revolve in planes so oriented relative to the line of sight that no eclipse can occur. These are the spectroscopic binaries, the duplicity of which is revealed from analyses of the light received from them by means of the spectroscope. Still more complicated are those systems which the telescope shows as double or multiple, where one or more components of the visual system are in reality spectroscopic binaries. Thus, the astronomer is able to discover that what appears as a single star to the unaided eye is in some cases a complex system of stars revolving about their centers of gravity, with periods from a fraction of a day to hundreds or even thousands of years. Such a system is Castor, the fainter member of Gemini, the twins. In this instance the telescope shows two bright stars exceedingly close together where the eye only sees what appears to be a single star. These two stars revolve about each other with a period of about 350 years. The third and fainter member of this same system is found a little farther away revolving about the common center of gravity probably with a period of more than a thousand years. Each of these three stars is a spectroscopic binary, so that in reality we have six stars belonging to a system where the unaided eye would see a single bright star. It is estimated that of all the stars in the sky, one of every three or four is a double or a multiple system. This is only one bit of evidence suggesting gregarious tendencies among the stars.

Astronomers believe that the distinction between visual telescopic double stars and the class of eclipsing and spectroscopic binaries is more real than apparent. Members of the former class have periods measured in years while those of the latter class, with a few exceptions, have their periods restricted below a hundred days. But why the difference? This is one of the questions of modern astronomy. Unless the universe is very much older than we believe it to be, near approaches and captures are not frequent enough to account for the large number of visual and telescopic doubles even if, under such circumstances, captures are possible. Serious doubts indeed arise if we assume that capture of one star by another may result from near approach. Probably the best suggestion is that visual doubles result from condensations about two separate nuclei in an early nebular stage of evolution. The revolution of one star about another, with reference to spectroscopic and eclipsing binaries as well as to visual doubles, is not more strange than the much more general fact now established by modern astronomy, that all the stars of the Milky Way system are revolving about their common center of gravity. To carry this idea further, it must also be concluded that visual and telescopic binaries were formed at a time when the Milky Way system was yet young and when all the stars were closer together than at present. At least we now see no evidence of the formation of such systems.

The question of the origin of eclipsing and spectroscopic binaries, according to some astronomers, has a close connection with the question of interrelationships of the different classes of variable stars: Jeans has proposed the theory that all variable stars are rotating and that when the period of rotation becomes sufficiently rapid, as in the case of the short-period Cepheids, the stars can no longer hold themselves together—an hypothesis known as the fission theory. If then a Cepheid is the parent of a binary system, how are we to prove it? Astronomical questions rarely lend themselves to direct proof, unfortunately, but any clue serves as a valuable bit of evidence either for or against a theory in question. We have evidence for extending the connecting links between long-period and Cepheid variables to eclipsing and spectroscopic binaries as well. We may mention: (1) there are spectroscopic evidences indicating rotation of Cepheids about their respective centers of gravity; (2) the mean densities of Cepheids are approximately what we should expect of two embryo stars in actual contact; (3) the mean radii of Cepheids compare favorably with the separation of the components of short-period binary systems; (4) slight evidences of correlations of colors and brightnesses of short-period binaries with Cepheids are to be found; (5) the agreement of periods is as good as can be expected, and (6) the space distributions of the two classes of objects compare favorably. These are necessary conditions substantiating the Jeans theory but they are not sufficient; they *prove* nothing. Arguments against the theory are also serious and difficult to meet. About the only alternative left for the fission theory proponent is to ask: What *are* the ancestors of this class of binary stars? Equally well may one ask the same question with regard to all double star systems. For the visual and telescopic doubles, however, the above conditions are neither necessary nor sufficient, and by no one is any relationship claimed between these stars and any class of variables.

In our own galactic system the total number of known variable stars given by the 1932 edition of Prager's catalogue is 5,461, about a large percentage of which nothing is known. A relatively large percentage of the remainder belong to classes of irregular or semiregular stars which may be intermediate between the various classes of periodic variables. We know practically nothing about these stars, since they demand series of observations more continuous than those now available. It is quite possible also that continuous series of observations made on all classes of variables would shed much light on the peculiarities and the causes of their variations which have hitherto escaped our attention.

Not only the professional astronomer but the amateur, likewise, can assist in answering astronomical questions. The part of the amateur astronomer is most strikingly manifested by the great work of the American Association of Variable Star Observers, composed of about 350 members working in this country and abroad, who in the course of a year report more than 25,000 observations on variable stars to its recorder, Mr. Leon Campbell, of Harvard College Observatory. By this organization more than a third of a million observations have been made on 500 variable stars, mostly of long period, and for the peculiar variable SS Cygni not a single maximum brightness during the last 35 years has escaped their notice. Besides this enormous program, a huge amount of variable star work is done at Harvard College Observatory by temporary employees who have other lines of activity and who do not claim to be professional astronomers. The field is a large one, and thus far we believe that we have done little more than penetrate the surfaces of the associated problems.

CYCLONES IN CONTINENTAL BATH TUBS

By EVALD ANDERSON
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THE old-fashioned European bathtub, with its outlet or drain in the exact center of the bottom, is perhaps not the most convenient type for the daily or Saturday night ceremony, but it does provide excellent opportunities for observations on cyclonic motions in water. The most striking thing about such vortex motions in water is their similarity in appearance to atmospheric cyclones, and it would seem to the amateur observer that a careful study of such easily arranged water-cyclones might well give valuable data for the meteorologists.

Nearly every one is no doubt familiar with such vortical or cyclonic motion in water, but perhaps not very many have attempted to make any systematic observations. The first thing which is impressed on the observer is the large rôle that chance seems to play in such vortex motions. The direction of rotation, for example, though apparently mostly following that of atmospheric cyclones, *i.e.*, contrariwise to the earth's rotation, may be first one way and then the other, under apparently identical conditions; and the same haphazardness seems to prevail in many other respects.

The starting point of such vortex motions seems, curiously enough, to be the upper surface of the water. With a light directly overhead, the first evidence is a small circular shadow cast on the bottom, from the moving surface layer. Then the familiar "cyclonic cone" begins to form and deepen, until it finally reaches the bottom and outlet. It is then very easy to impart a to-and-fro motion of the water and simulate, almost exactly, the motion of a cyclone over the surface of the plains.

In this manner it is easy to see the reason for the absence of cyclones in hilly regions (assuming of course that such observations on water are applicable also to air). Thus if the lower tip of such a vortex, moving over the lower surface, strikes a projection protruding but a little over the bottom, the vortex motion is immediately destroyed.

In the particular case where most of these observations were made there seemed to be a close relation between the depth of the water layer and the probability of the formation of cyclonic motion. Except when initiated artificially this motion hardly ever started with a layer deeper than nine inches, but practically always started immediately if the layer was of half that depth.

As already stated, the direction of rotation is probably "counter earthwise" when not influenced by other factors. It was always so in one case, though subsequent observations elsewhere cast some doubts on the correctness of such a generalization. It is rather startling that confirmation of the rotation of the earth can be had by such homely means.

Vortex motions in water are naturally of great interest to the hydraulic engineer, and have also been made use of in the study of the flow of gases, but the only reason for discussing these particular amateur observations is their possible bearing on the study and prevention of atmospheric cyclones.

One might assume from such observations that a necessary condition for atmospheric cyclones is the existence of a fairly quiet layer of air with low pressure near the earth's surface and a similarly quiet layer of high pressure some distance above the earth. These conditions can, of course, be brought about by reradiation of long wavelengths from the earth's surface to the adjacent gas-layer. It is well known that such layers of a heavy fluid over a lighter one can persist for appreciable periods. Nearly always these layers will probably in most cases finally mix more or less quietly through convection, but occasionally there might be formed something like a hole in the intervening layers, permitting the heavier air above to stream downwards to the region of lighter air below. Such a downward motion is then easily converted to the vortex motion. When then this intervening layer of air with its "hole" is moving over the surface of the earth we have the familiar cyclone cutting its path across the plains.

If the above picture is at all correct, it should be possible to devise methods for the prediction and perhaps prevention of disastrous cyclones. Assuming that it could be proven that a minimum pressure difference or a minimum height of a heavy air layer is necessary before such a cyclonic stream can start, then measurements of the atmospheric pressure and temperature at different levels during the cyclone season might produce useful data for such prediction.

But even though reliable prediction could be developed the ultimate aim must of course be prevention. We are perhaps too prone to assume that interference with such natural phenomena is impossible. Considering that only a slight projection from the bottom of a vessel of water suffices to stop cyclonic whirls in this medium, it might be possible to erect "cyclone walls" around the towns on our plains instead of cyclone cellars under them, for it is conceivable that such man-made obstructions of only moderate height would serve to protect adjacent lower structures. Furthermore, an observer of such motions must be impressed with their great instability since seemingly slight disturbances often suffice to entirely destroy the vortex motion, even though the downward motion persists. That being so it might be possible to so disturb an actual atmospheric cyclone as to stop the vortex motion long enough so that the disturbance can pass over a city without doing serious damage. For example, it would be interesting to try the effect of the modern explosive gas-shell on the tip of a cyclone, and it should be possible to devise a shell which could be exploded in the air without damage to the country below. Should such a scheme prove practical the fire-departments of the cities in our cyclone regions might ultimately have artillery brigades that would go out in defense of their towns when a cyclone approached. It is reported that such cyclonic disturbances on the ocean, commonly called water-spouts, have been destroyed by gunfire from warships so that there would be precedence for using artillery on land for this purpose.

The cyclonic disturbances herein discussed are naturally the minor ones commonly called cyclones or water-spouts. When we consider the larger atmospheric cyclonic motions commonly called "lows" where the average radius of the path of the moving air at the surface of the earch is measured in miles, the conditions are, of course, entirely different. These disturbances are, as a matter of fact, not broken up by the ordinary size obstructions, since those coming from the Pacific Ocean appear to pass over both the Coast Range and the Sierra Nevada Range without diminished activity. However, if some means of prediction and prevention of the smaller cyclones could be found, the gain in safety and comfort of the dwellers of the plains might still be enormous.

WASHINGTON SETS A RIVER ON FIRE

By Dr. **NORMAN J. HARRAR**
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A MEMORABLE experiment was carried out during the evening of November 5, 1783, on a little river north of Princeton, for with it is associated the name of George Washington. The first feeble attempts to employ scientific methods in those early American days are of interest to the historian but this particular story has a far wider appeal.

Any description of this experiment should be preceded by an account of the fortuitous series of events which led to its performance.

The summer and autumn of the year 1783 brought happy days to the commander-in-chief of that first American Army. Active military operations had practically ceased after the decisive victory at Yorktown and peace negotiations had long been in progress. A remarkably complete attainment of the dreams of independence was soon to be realized. This full achievement of purpose must have been a source of peculiar satisfaction to the tired general.

Late in the month of June of this year, owing to an unpleasant attitude on the part of some of the troops, Congress had rather hastily moved from Philadelphia to Princeton. In the seclusion of this quiet little town, deliberations continued upon the treaty of peace. About the middle of August, Washington was asked to come to Princeton to advise upon various details of the final terms. Acting upon this request, he left his army under the command of General Knox at Newburgh, and, with a portion of his military family, put himself at the disposal of the assembly.

A house was provided for Washington and his staff at "Rockingham," the estate of Judge Berrien's widow near the village of Rocky Hill, three or four miles north of Princeton. The dwelling was pleasantly situated upon an eminence, a few hundred yards east of a small stream known as Millstone River. These quarters were comfortable and conveniently located for the frequent contacts necessary with the sessions of Congress. In addition to the delegates engaged in the regular meetings, Washington entertained many persons of note during nearly three months of residence. He was able to relax somewhat from the long strain of work and worry, and by all accounts it was a most agreeable interlude.

Not so far away, but living under very different circumstances, was another leader of the independence movement, Thomas Paine. His writings had been of great importance in arousing the people of the colonies, and his services abroad had been equally valuable. Some of his friends had reminded Congress of its definite obligations to him, but he had gone almost entirely unrewarded. At the time, he was embittered perhaps as much by the unfairness of this neglect, as by the burden of real poverty. One day he received a heartening letter:

> Rocky Hill, Sept. 10, 1783.
>
> Dear Sir,
>
> I have learned since I have been at this place, that you are at Bordentown. Whether for the sake of retirement, or economy, I know not. Be it for either, or both, or whatever it may, if you will come to this place, and partake with me, I shall be exceedingly happy to see you.
>
> Your presence may remind Congress of your past services to this country; and if it is in my power to impress them, command my best services with freedom, as they will be rendered cheerfully by one who entertains a lively sense of the importance of your works, and who, with much pleasure, subscribes himself,
>
> Your sincere friend,
> G. Washington.

This friendly letter was entirely worthy of the great man who wrote it and naturally brought real happiness to Paine, who was only too glad to accept such a kind invitation. Thus it was that he journeyed to Rocky Hill, where he received a warm welcome and where he remained during the period of Washington's residence at that place.

A number of Paine's old comrades were there to greet him; among them were Colonel Humphreys and Colonel Cobb, who were at that time aides-de-camp to the commander, and also General Benjamin Lincoln. Apparently it was not long until Paine was in good spirits again because, true to his nature, he was soon involved in an argument.

It seems that the natives of the district had been amazing the officers with a peculiar story regarding the river or creek that ran so near to their quarters. The reports were that it was possible to "set the river on fire," to give the exact manner of speaking of these people. This was done, so they said, by disturbing the mud at the bottom of the river and then holding some blazing material, such as paper or straw, a little above the surface of the water.

Upon hearing this strange tale, Paine attempted to advance an explanation as to the cause of the mystery, and at once became entangled in a friendly argument with Colonel Humphreys and Colonel Cobb. The opinion held by the two officers was that, on disturbing the bottom of the river, some "bituminous matter" arose to the surface, which took fire when the burning substance was put to it. The theory developed by Paine was that a quantity of so-called "inflammable air" was set loose by stirring the mud on the river bottom and this ascended through the water and took fire as it left the surface. It seems that the truth of the reports about the river and the existence of some sort of combustible material was not questioned. Rather the dispute involved the nature of the peculiar substance, or more particularly, as to whether or not it existed in a gaseous form.

Apparently all this discussion aroused the interest of Washington, who made the sensible and practical suggestion that they all go down to the river and put the matter to a test. To quote the description written by Paine sometime afterwards, "General Washington had a mind to try the experiment." The necessary preparations were made by General Lincoln and everything was ready for the experiment to be tried out on the evening of November 5. The following description of this adventure is taken from a portion of the account written by Paine himself.

> A scow had been stationed in the milldam, and General Washington, General Lincoln, and myself, and I believe Colonel Cobb (for Humphreys was sick), and three or four soldiers with poles, were put on board the scow. General Washington placed himself at one end of the scow, and I at the other; each of us had a roll of cartridge paper, which we lighted and held over the water, about two or three inches from the surface, when the soldiers began disturbing the bottom of the river with poles.
>
> As General Washington sat at one end of the scow, and I at the other, I could see better anything that might happen from his light, than I could from my own, over which I was nearly perpendicular. When the mud at the bottom was disturbed by the poles, the air bubbles rose fast, and I saw the fire take from General Washington's light, and descend from thence to the surface of the water, in a similar manner as when a lighted candle is held so as to touch the smoke of a candle just blown out, the smoke will take fire, and the fire will descend and light up the candle. This was demonstrative evidence, that what was called setting the river on fire, was setting on fire the inflammable air that arose out of the mud.

It is evident that this experiment on the river gave results which supported the opinion that the combustible substance was in the form of a gas. However, mention should be made of the fact that the chemical composition of this gas was unknown at the time, and the confusing term, "inflammable air," was being applied rather indiscriminately to various combustible gases. It was some years before the more specific name of "marsh gas" was generally used to designate the material tested in this experiment. Although certainly neither of them realized it, Washington and Paine were investigating the properties of a substance which had yet to be identified as the organic compound whose simple molecule is the basis of thousands of derivatives.

The experiment was not forgotten by Paine and he planned to follow it up with further research. Upon his next visit to Philadelphia, he described the results of these tests to David Rittenhouse, the scientist who succeeded Franklin as president of the famous American Philosophical Society. Together they continued the study of the properties of this "inflammable air," employing somewhat more exacting methods.

A report of all this work was finally published in a paper addressed to the "Board of Health in America," and entitled, "Of the Cause of Yellow Fever and the Means of Preventing It in Places Not Yet Infected With It." At this time there were frequent and severe plagues of yellow fever, the causes of which were not understood, although it was beginning to be recognized that there was some relation between the existence of marshy lands and the appearance of the disease. The theory advanced by Paine developed the idea of this relation and then attempted to trace the cause to various noxious emanations, particularly his "inflammable air," produced in swampy areas. Considering the amount of information available in his day, this opinion was by no means absurd. As a matter of fact, several noted authorities, especially Dr. Samuel L. Mitchill, and later, Alexander von Humboldt, famous tropical expert, suggested very similar explanations. Almost a century passed before any better solution of the problem was offered.

The experiment was probably not entirely forgotten by Washington, who had a most retentive memory for information of this nature. Just ten years afterwards, he might have thought once more about its relation to health and sanitation, for, about the middle of August of the year 1793, the capital city, Philadelphia, was visited by a terrible plague of yellow fever. He remained in the city for some weeks after most of the officials of the government had fled, but was finally persuaded to go to Mount Vernon.

The progress of the disease in Philadelphia was watched by the President with great anxiety, and his letters of this period are filled with the subject. He was particularly worried about the meeting of Congress, scheduled for December, and he considered the possibility of holding the sessions elsewhere. He expressed the hope that heavy rains would come, but it was the frosts of November that finally relieved the city. Naturally it is impossible to determine just how familiar he was with the current theories regarding yellow fever, but Washington undoubtedly understood the practical aspects of the situation.

The experiment made that November night should be remembered, even though the participation of Washington insures its fame. It was a simple thing to do, the results were not worth very much, they were even used to support a theory that turned out to be quite misleading. Nevertheless, there is something in the story eminently worth remembering. A certain characteristic attitude was brought out in the course of all the discussion and argument about possible explanations of the strange reports—"General Washington had a mind to *try the experiment.*"

SCIENCE SERVICE RADIO TALKS

PRESENTED OVER THE COLUMBIA BROADCASTING SYSTEM

SOME RECENT ADVANCES IN MEDICINE AND PUBLIC HEALTH

By Dr. G. W. McCOY

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WHEN Science Service assigned this subject to me it gave me a great deal of latitude as to the period of time that might be considered as "recent" in reference to progress in certain medical problems.

In a general way, I shall confine my remarks to advances that have been made during the last ten years, or, at least, to those that have received practical application within that decade. I shall omit any reference to surgery and medical specialties.

Progress in medical science is generally made in one or both of two ways: First, we have the careful study of disease in man by which we endeavor to discover the cause, means of prevention and mode of treatment by observation on the patient, study of his history, and of the effects of treatment. The second method you might speak of as the experimental one, in which the subject of experimentation may be man himself, or we may utilize the lower animals. A good example coming under the first head—that is, experimental work on man himself—is to be found in the observations of the great Jenner on the prevention of smallpox by vaccination. It was traditional in the country in which Jenner practiced medicine, for he was a practitioner in a rural community, that persons who had suffered from a particular disease of the hands derived from cattle did not take smallpox. Jenner put the truth of this tradition to the crucial test of experiment by inoculating a boy with cowpox and then, after a few weeks, inoculating him with smallpox material. The result was just as Jenner had expected it would be, the boy did not take the smallpox. Thus, by a single, simple, well thought out experiment on a human being the foundation was laid for a public health procedure which probably has done more in the way of preventing suffering and disability than any other one discovery in the field of preventive medicine, for you must remember that before Jenner's day smallpox was extremely prevalent compared with the present day and the death rate often was terribly high.

The second line of experimental attack on a problem involves the use of animals. I might give you many examples of this but I think one will suffice to illustrate the point. Through the means of experiment which involved the use of a good many dogs, the substance which we now know as insulin was found to have a very pronounced, beneficial, effect on diabetes. This substance is not regarded as a cure for diabetes but in many cases it does effectively control the symptoms and permit the individual to lead a useful life over a period of many years. To illustrate how well discriminating scientists think of this discovery for the treatment of diabetes, I may mention that the Nobel prize was awarded to Dr. Banting, whose brilliant experiments gave us this valuable remedy.

Finally, in this introduction, I should like to refer to the work of the late Dr.

Goldberger. His experimental investigation involved the use of both man and laboratory animals. I shall go into a little more detail in this respect a little later.

The order in which I shall consider some of the more recent advances is not to be taken as an indication of the relative importance of these advances. Some of the advances I am going to mention depend for their application on medical guidance by the well qualified physician. A few of them, however, deal with phases of subjects in which the person without medical training may profit greatly.

I suppose the most striking of the advances we have made is in respect to a comparatively rare disease, but one which proved invariably, or almost invariably, fatal prior to the studies of recent years. I refer now to pernicious anemia. Through a combination of very carefully designed experimental work on dogs and equally careful clinical work on patients, a most effective remedy for this disease was found in so commonplace a substance as the liver of animals that furnish us with meat for food. The physician now confronts the case of pernicious anemia with a feeling of the utmost confidence that he will be able to bring the condition under control. True enough, he will not be able actually to cure his patient but so long as liver, or one of its derivatives in the shape of liver extract, is available the symptoms can be controlled and the blood of the victim, which may have fallen to 20 or 30 per cent. of normal, may be brought back to the figure that is normal, or substantially so. So impressive are the results of the treatment of this hitherto incurable disease that one of the popular magazines awarded a prize of ten thousand dollars to be divided between Dr. Whipple, the experimental scientist who carried out the work on animals, and Dr. Minot, the skilful physician who carried out the bedside observations.

More recently another material has been found which is about equally effective with liver. This is the substance of the stomach of the hog. From the economic point of view this is a matter of some consequence because, as I am sure you all know, since the liver treatment of pernicious anemia became popular the price of liver has become quite high.

The progress in relation to the elements in food which we call vitamins is so rapid that one must specialize in this particular field to keep abreast of it. I shall refer to only one, the one that is of great importance particularly in the South. I have in mind now the vitamin the lack of which is responsible for the all too common disease called pellagra. The studies that led to the discovery of this fact—that is, that pellagra was due to the lack of a vitamin—illustrate the type of thorough research in praise of which one cannot be too enthusiastic. When Dr. Goldberger began his studies on the prevention and cure of this disease many physicians believed it contagious or infectious. The keen mind of Goldberger speedily saw that this question could be readily put to a test by dietary studies following two general lines: First, he sought to produce pellagra in volunteers by feeding a diet especially designed for that purpose, and succeeded in this. Next, he went to institutions in which pellagra was occurring with great frequency, and by suitable modifications of diet succeeded in wiping out the disease completely in those institutions. Then, to put the infectious theory to even a more severe test, but from a different angle, he tried to produce pellagra in volunteers, including himself and many of his friends, by the feeding of material from pellagrins, material which should have caused the disease in the volunteers if the disease could be carried from one person to another. He failed to produce pellagra in this manner. The results of the studies of this brilliant worker have been accepted without question by those competent to judge throughout the world, and pellagra has become one of the most readily controlled of all the diseases physicians and public health authorities are called upon to combat. That in practice it is not always controlled is due to dietary habits and economic conditions which will require a long time to remedy.

I cannot refrain from mentioning a by-product of Goldberger's work, a by-product which was not foreseen by any-one working on the subject. This was a discovery of tremendous interest to veterinary scientists and of the greatest value to dog fanciers and dog owners. I refer to the condition known to those familiar with the diseases of dogs as blacktongue. The cause of this was quite unknown prior to Goldberger's work. It was a malady that killed large numbers of dogs, especially in the South. This is a condition of dogs in many respects similar to pellagra of man. Goldberger proved that the cause was similar to the cause of pellagra, that is, that it was due to a diet deficient in some essential factor and that it was readily prevented and quickly cured by a suitable modification of the diet. If Goldberger's work on animals had failed us in respect to human pellagra, it would still be of enormous value purely from the viewpoint of the health of dogs.

I have just illustrated how a research designed primarily to control a disease of man has proven of inestimable value to lower animals. Now, let me give you the reverse of this:

Every one knows, I am sure, that the hookworms of both dog and man cause very serious conditions, often disabling the man, woman or child, and often killing puppies. Now, we have for a long time had fairly effective treatments for hookworms applicable both to dog and to man but they were far from perfect and did not always remove all of the worms; and, what was perhaps most serious, sometimes themselves proved poisonous to the patient, human or canine. Dr. Maurice Hall, of the Bureau of Animal Industry, approached this subject primarily in the interest of the dog, seeking to improve the treatment available for hookworms of that animal. His experiments were carried out on dogs and consisted of administering to individual dogs and to groups of dogs, various chemical agents which he hoped might prove effective. He found a more effective agent than any known before and it was soon found to be an improvement on the treatment of hookworm of man as well as of dogs. Many would have been content to stop there, but Dr. Hall is a true scientist and was unwilling to stop short of perfection, or as near perfection as he could attain. His work was therefore continued and another drug was found that was equally effective in curing the dog and safer for the patient. I tell this to illustrate why those interested in advancing the welfare of man and of animals continue experimental work even after progress has been made. I suppose the worst thing that could happen to medical and veterinary science and public health as it affects both fields would be to regard anything as permanently settled. We must constantly endeavor to improve the means already at our disposal for the prevention and treatment of disease.

The next subject is one that might be spoken of as a new disease, or, perhaps, a disease newly recognized insofar as concerns us in the United States. I refer to undulant fever, sometimes known as Malta fever—although this name is unsatisfactory because the disease prevails far beyond the borders of Malta. We know now it is tolerably prevalent in the United States, although a few years ago we knew nothing of it save that occasionally some one in the southwestern part of the United States was infected from goats. We know now that people often are infected by handling diseased swine or cattle. Sausage makers seem to be especially likely to get the disease from handling the carcasses of hogs. One of the most controversial points in respect to this disease is as to just how far the infection is due to cow's milk. The evidence suggests that perhaps half of the cases we have in this country are derived from milk. The prevention of milk-borne undulant fever is quite simple: Use only pasteurized or boiled milk and there will be no danger. That this really works in practice is evident by the fact that in communities in which all milk is pasteurized the disease is unknown, while individual cases and small outbreaks occur when milk is not pasteurized. Of course, there are other good reasons for the pasteurization of milk; the risk of undulant fever is to be looked upon as an *additional* reason. The prevention of the cases not due to milk, those due to contact with infected animals or animal products, is unsatisfactory. It is encouraging, however, to know that veterinary scientists are steadily going forward in research in this important field and that we may look hopefully to the time when the disease in animals can be either abolished or brought under very definite control—and thereby the source of human infections will be eliminated.

I suppose one of the most important advances made in medicine within recent years has been with reference to the prevention of diphtheria by specific immunization. We have had for many years an effective treatment of diphtheria in the shape of antitoxin. The death rate was thereby greatly lowered but still the number of cases continues distressingly high. It is possible at the present time, through immunization of children, almost to guarantee that a treated child will not be attacked. In some communities in which diphtheria prophylaxis has been in use by health authorities the number of cases has been reduced nearly to the vanishing point. Physicians everywhere are now encouraging parents to have their children immunized before the school age since it is in the earlier years that diphtheria is the most prevalent and most frequently fatal.

I am going to conclude my remarks by referring to one of the most interesting and important pieces of work with which I am acquainted. For some years there has been occurring in the Eastern and Southeastern States an eruptive disease which was regarded as typhus fever, not quite so severe as the typhus long familiar to physicians as "camp fever," "jail fever," or "ship fever," but still essentially the same. On the basis of keen medical observation of patients and well thought out experimental work it has been shown that what we in the vicinity of Washington and adjacent territory were calling typhus fever really embraces two diseases: One, typhus proper and the other a disease that is identical with, or at least not to be distinguished from, the spotted fever of the Rocky Mountain region. Now this might be a matter of interest only to students of medical sciences but for the fact that the differentiation of the two diseases was accompanied by the throwing of much light on the modes of transmission. It has been shown that typhus, which in Europe is conveyed by the body louse, in this country probably is conveyed by fleas and possibly by other parasites. On the other hand, and this is very important, the indications all point to the Rocky Mountain spotted fever type of infection as being carried by ticks in our eastern states just as it is carried by ticks in the west. If further research confirms what now seems probable in regard to the sources of infection of these two diseases, we have in our hands easy means of prevention.

HUMAN VARIATIONS

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THAT no two human beings look exactly alike is a well-established fact. Even in so-called identical twins one can detect many differences by exact and detailed comparisons. Thus, every man represents a variation, which means a deviation from the typical or average condition of the particular race to which he belongs. To be more precise: every individual represents really a special combination of many variations, since every part of the body can vary more or less independently. For example, if we study stature alone we can find many individuals of a series studied who do not differ from one another in this feature. If, however, we were to arrange this series according to stature *and*, let us say, chest circumference, the number of corresponding individuals would become much smaller. If, finally, we should consider twenty, instead of only two, bodily characters, it is most unlikely that any two individuals would show exactly the same variations in all the features examined.

What are the underlying causes and what the effects of this tendency of the human body to vary in all its parts and this frequently with surprising intensity? We cannot claim to have as yet found the final answers to these fundamental questions, but we have collected a mass of information on the nature of variations which is of great interest in itself and which at least points in the direction of an ultimate solution.

There exists a wide-spread belief that individual differences become more and more pronounced with advancing age under the direct influence of differing occupations, diets and other environmental factors. Such a view, however, agrees in no way with the facts observed. Anthropologists have long ago realized that all men are not born equal but differ from one another at least as much at birth as in adult life. Indeed, long before birth, when the body is less than an inch in length, one can already distinguish individuals with proportionately long limbs and slender trunks and those with relatively short limbs and stout trunks. Individual differences in the shape of the nose, mouth, ears, hands, and in other parts of the body are as clearly defined at early stages of development as at the completion of growth. We can not, therefore, hold environmental factors responsible for all these variations. This is also borne out by the finding that wild monkeys in their native jungle vary as extensively as do human beings under the diverse conditions of civilization. Among several hundred monkeys of one species, collected in the uniform environment surrounding one camp in the forest of Nicaragua, I found specimens with pug noses and those with straight profiles, some with large ears and others with small ones. In short, they differed from one another as widely as would an equal number of human city-dwellers and this in spite of the fact that these monkeys all had the same occupation, the same diet, and the same climatic conditions, etc., and this during thousands of generations.

With environment ruled out as the primary cause of human variations we have to examine the question whether heredity is the basis of them. It is not necessary to explain that many individual traits are readily understood to be the result of the combination of differing hereditary patterns in the parents. Heredity alone, however, will not explain all variations. This is evident from a study of the exact mode of resemblance between single-ovum twins, who theoretically are endowed with identical hereditary qualities. If such twins are examined and measured with accurate instruments it is found that frequently they differ from each other very significantly, and this not only in adult life but also before environmental factors could have exerted a noteworthy influence, namely during their embryonic stages of growth. Just as twins, developing from the two halves of one and the same ovum, are often not alike, so are the two halves of the same body rarely of exactly corresponding size and shape. Such asymmetries are well known to exist in the length of the arms, the right one usually being longer than the left. This is commonly held to be a consequence of right-handedness, which is supposed to give a special growth stimulus to the right arm. However, asymmetries occur in practically all parts of the body and can be particularly marked in such structures, as the outer ears, which have no more function on the right than on the left, as has the hand. Furthermore, asymmetries, which really represent nothing but variations in the two halves of the body, occur in the apes as well as in man and are fully as pronounced in embryos as in adults. It is evident that heredity alone can not account for all variations, but it is known that many variations are transmitted by heredity. The universal tendency to form individual variations, that is to deviate from the average condition, must be regarded as representing *primarily* a force in itself, existing in spite of heredity and independently of environment, but either accentuated or subdued by the latter two factors.

It is most significant that different parts of the body vary with widely differing intensity. In the white race, for instance, the color of the skin varies not nearly as much as the color of the hair or of the eyes. The proportion between the lengths of the upper and of the lower limbs is not nearly as variable as the proportion between the length of the limbs and that of the trunk. The number of vertebrae in the neck region of the spine is constant with very few isolated exceptions, but the number of vertebrae composing the lowest region of the spine varies tremendously. Generally speaking, it can be stated that the more variable a particular structure the more it is apt to undergo possible changes in the future or to have changed during the past. On the other hand, comparatively uniform structures have little chance for new adaptations because they fail to provide new possibilities for selection.

In many structures we can recognize in the range of individual variations the trend of evolutionary modifications. To mention just one of many available examples: There exists abundant evidence for the conclusion that man once possessed a tail containing more vertebrae than have persisted in vestigial form to this day. The reduction in these vertebrae has not progressed equally far in all individuals, in some men six are still retained, whereas in others this number has already dwindled to four or even only three. The former case represents a primitive or retarded variation, the latter a progressive variation. In the orang-utan this evolutionary degeneration of the tail has reached an even greater extreme, and the pendulum of variations has shifted, swinging no longer between six and three vertebrae, as in man, but between only four and one. In many instances it is impossible to give a plausible reason for the selective value of such variations. If we call some rare variation "primitive" just because it corresponds to the most common variation in an ancestral form, it does not necessarily imply that this condition has become disadvantageous to its present owner and might for this reason become eliminated by one form of selection or another. Many, if not most, variations are in themselves entirely inconsequential to the individuals possessing them. Nevertheless some may gradually become eliminated, whereas others may appear with increasing frequency in later generations, not because they are "good" or "bad," but because they regularly happen to be associated with some other variation of a decidedly selective value. Such quite definite combinations of certain variations in morphological and physiological features are recognized as constitutional patterns. If such a pattern or type includes but one fatal variation, such as a high susceptibility to some disease, all the other, indifferent, associated variations will be carried along in the eliminating process of selective mortality.

It may bluntly be claimed that without variations there would be nothing to select from and without selection there could be no progress or at least no lasting change in, or evolution of, our physical make-up. A multitude of selective factors is continually at work among constantly occurring human variations. Some of these factors have lost their efficiency with advance in civilization, but that very advance has introduced new selective processes of sometimes very doubtful benefit to the human race. It is most essential that all these selections be carefully investigated so that we shall become able to place them under our control.

CROPS AND CIVILIZATIONS

By Dr. E. D. MERRILL

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THE title of this article is a very comprehensive one, and within the limits of space available to me only certain aspects of the subject can be presented. There is, however, a distinctly interesting series of correlations which I shall attempt to summarize in this brief address. It is self-evident that agriculture is basic to all advanced civilizations. It is equally evident that all cultivated plants and all domesticated animals were derived from wild ancestors, some time during the development of the human race and, for the most part, early. We are apt to take our cultivated plants and domesticated animals for granted and seldom give a thought to whence they came, when, where and by whom the plants were brought into cultivation and the animals domesticated, how, when and by whom they were disseminated. The facts are in general approximately known, but the inferences to be drawn from these facts are too often ignored.

It is well known that practically every cultivated food-producing plant and all domesticated animals now found within the limits of the United States were introduced from other regions. Some years ago while residing in the Philippines it occurred to me that in that strictly tropical archipelago, covering a water area of approximately 600,000 square miles, the same statement was true; that all the cultivated food-producing plants and all domesticated animals now found in that archipelago were exotic, having been introduced in the past from various parts of the world, some in the prehistoric period, others within historic times. It was found that other very large areas in various parts of the world presented the same story. It gradually dawned upon me that here was a fertile field for investigation. In reference to the United States, the Philippine Islands and other large areas in the world the questions arise: Where did these agricultural plants and animals originate? When, how and by whom were they introduced into the regions where they now occur? What limitations, other than climate, inhibited the universal distribution of important food plants and animals up to about 500 years ago?

It is well known that every important food-producing cultivated plant was already in cultivation and every important domesticated animal was already in domestication at the dawn of recorded history. In the agricultural experience, slowly built up by many peoples through the long period of pre-history, was laid the basis of all civilizations. It is, of course, axiomatic that before a civilization could develop anywhere, there must be a constant and dependable food supply, and this our remote ancestors insured during their long period of agricultural development. While modern man has accomplished much in plant and animal breeding, increasing quality and yield, and ensuring a more dependable food supply through breeding for disease resistance, yet after all it may be doubted if any modern development in plant and animal breeding equals the accomplishments of our very remote and uncultured ancestors who brought the very numerous plants and animals basic to agriculture in from the wild and developed them to serve their needs under domestication. It is rather strange that, in spite of the tremendous advances man has made in the past few hundred years, in this period, outside of numerous ornamentals, he has actually domesticated very few species of plants and no animals; and the few plants domesticated are not food-producing ones, but rather those which yield products in great demand in modern trade, such as *Cinchona* (quinine), *Hevea* (Para rubber), abacá or Manila hemp, and other medicinal, oil and fiber producing plants. The culture of many species has been very greatly extended, such as coffee, tea, cacao and numerous others, but these were all in cultivation many centuries ago, either in Eurasia or America, but none were known outside of the continental areas where they originated before the advent of European exploration.

If one surveys the world in relation to the places of origin of agricultural plants and domesticated animals, it becomes evident that vast areas originally produced nothing of consequence in the plant or animal kingdom as far as agriculture is concerned. Thus all North America north of Mexico, all Australia, much of Africa, and large areas in Asia, Europe and South America added practically nothing to our stores of plants and animals basic to agriculture. The centers of origin of the more important species are peculiarly restricted and, what is perhaps of even greater interest, these centers of origin of agricultural products correspond rather closely with those regions in which ancient civilizations were developed. A combination of favorable climatic conditions; native plants or plants and animals of importance in the production of food and that were more or less readily adapted to domestication as a basis of a permanent food supply; potential mental ability on the part of the local pioneers of civilizations; and, perhaps, fortuitous circumstances, all had their part in this period of pre-history, as far as man and his civilization is concerned.

The centers of origin of civilizations and of agricultural plants in America are in general two rather restricted regions with equable climates; the highlands of Mexico in North America, and of Peru in South America, with a more tropical subcenter in Central America and Yucatan; in Eurasia, Asia Minor, certain parts of the Mediterranean basin, and restricted areas in India, China and central Asia correspond to the few centers of origin in America. And what is again of distinct interest is that in these centers of the beginnings of ancient cultures the independent civilizations were built primarily on the basis of certain definite plants and animals native of each region. Thus in Peru, the potato and various beans were basic; in Mexico, the most important food plant was maize, or Indian corn; in Asia Minor, and perhaps in some parts of the Mediterranean basin, the basic foods were our standard cereals, barley, wheat, rye and oats; and in India and in China, rice. In each center there were, of course, secondary food-producing plants, including various vegetables and fruits and in most or all centers certain animals were of distinct importance.

Without going into detail it is of interest to note in general the origin of basic agricultural plants and animals, as between the old and the new worlds.

The food plants of Eurasian origin are the common cereals, such as wheat, rye, barley, oats, rice, millet, Italian millet, sorghum, pearl millet and others of minor importance, such as ragi, teff and coix; in this category for convenience buckwheat may be placed, although it is not a true cereal; among the vegetables are the turnip, cabbage, rape, radish, beet, parsnip, carrot, onion, leek, garlic, shallot, spinach, egg-plant, lettuce, endive, salsify, celery, asparagus, pea, soy-bean, cow-pea, chick-pea, pigeon-pea, lentil, broad-bean, hyacinth-bean, asparagus-bean, taro and the yams; among the fruits are the apple, pear, plum, cherry, European grape, apricot, peach, prune, olive, fig, almond, persimmon, quince, pomegranate, melon, watermelon, cucumber, and in the warmer regions the banana, coconut, all citrus fruits, including the orange, lime, lemon and pomelo, date, mango, bread-fruit, jakfruit, rambutan, litchi, longan, lansone, mangosteen, and others. The domestic animals of Eurasian origin include all breeds of cattle, horses, water buffaloes, yaks, sheep, goats, swine, ducks, geese, hens and pigeons. These are the basic agricultural foods of the entire eastern hemisphere. Of course, many of them are limited in their range by climatic conditions, and from the standpoint of European civilizations, many of the plants that will thrive under European climatic conditions, and some of the animals, did not actually reach Europe until well into the period of recorded history; some were introduced in very modern times. The point I wish to make is that they are all natives of some part of the Old World and none were known in America previous to Columbus' voyage in 1492.

While the list of food plants and domesticated animals native of Eurasia is an impressive one, certain very important items are lacking; these are essentially the agricultural products on which the American civilizations were based. The basic food plants of American origin include but one cereal, but this is a very important one, maize or Indian corn; in addition, there are such vegetables as the potato, sweet potato, lima bean, all varieties of our common garden and field beans, tomato, pepper, Jerusalem artichoke, squash, pumpkin, quinoa, peanut, and in the more strictly tropical regions cassava, arrowroot, chayote and such fruits as the papaya, avocado, pineapple, custard-apple, soursop, cherimoya, sapote, sapodilla, cacao, cashew, and others. The domesticated animals were peculiarly few, the llama and alpaca in South America, and the turkey in Mexico. These are the basic agricultural products on which the American civilizations were based, and none of them were known in Europe or Asia previous to 1492, even as none of the longer Eurasian list were known in America before that date.

Various problems appertaining to ancient civilizations in America have intrigued many investigators, and numerous theories have been proposed to explain certain resemblances between these pre-Columbian American civilizations and those of Eurasia on the basis of supposed contacts across the Atlantic and the Pacific. It is, however, a curious and incontrovertible fact that previous to 1492 not a single cultivated food plant of major, or even secondary, importance, or a single domesticated animal, except the dog, was common to both hemispheres.[1] Briefly, this means that agriculture was developed independently by primitive man in America strictly on the basis of American plants and animals and that the early American civilizations were developed on the basis of this agriculture. It is only within the past five centuries that there has been a general world-wide dissemination of the basic food plants and domesticated animals. The resemblances between the early American and the Eurasian civilizations are apparently only fortuitous. The conclusion that one draws on the basis of biogeographic distribution of plants and animals basic to agriculture is that there were no contacts of importance between Eurasia and America previous to 1492. Had there been in the long period of pre-history only fortuitous and accidental contacts, and these only at long intervals, after the development of agriculture, the first items to be transmitted across the ocean would be seeds and tubers of food-producing plants, that is, those items essential to the maintenance of life, rather than the more advanced arts of architecture, hieroglyphic writing, and political, civil and ecclesiastical organization. It is the history of primitive invading or colonizing peoples in such vast areas as Malaysia and Polynesia that they took their food plants with them in their migrations, just as at a later date Europeans colonizing America brought their familiar agricultural plants and animals with them, and established them in their new homes. It is certain that, had any considerable number of these agricultural items of Eurasia been transmitted to America before 1492, or *vice versa,* at least some of them would have persisted in cultivation in their new homes, so that when Europeans actually commenced the exploration of America they would have found somewhere cultivated food plants with which they were familiar at home. What they did find was an agriculture based on a series of plants and animals totally unfamiliar to them and for the most part representing natural groups (genera) different from those of Europe and Asia.

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[1] The gourd, *Lagenaria vulgaris,* is the only cultivated plant regarding which we have incontrovertible evidence of ancient cultivation in both tropical America and tropical Asia and Africa before 1492, but this plant is of very minor importance from the standpoint of food. It was probably disseminated by ocean currents from whatever may have been its original home. There is some evidence that the peanut occurred in Africa before the European exploration of America commenced and, if so, it must have been transmitted across the Atlantic by man. Similarly, there is some evidence that the sweet potato may have been introduced into Polynesia by the Polynesians from America previous to the advent of Europeans in the Pacific basin, but the evidence is not very conclusive. Those theorists who have claimed the coconut to be native of America, and that the banana was in cultivation in tropical America before 1492, have based their arguments on totally inadequate evidence, and their arguments in each case have been most successfully refuted. In passing, it may be noted that tobacco is also native of America and was unknown in the Old World before Columbus' voyage, although here again at least one theorist has proved to his own satisfaction that tobacco originated in Africa, or that it was present in Africa before 1492, and others have made similar claims for New Guinea, at least to the extent that the practice of smoking tobacco originated independently in New Guinea on the basis of an indigenous species of tobacco. See E. D. Merrill, "Tobacco in New Guinea," *Amer. Anthropologist,* 32: 101–105, 1930, where this ethnological myth is explained.

SIMPLIFYING OUR CALENDAR

By Dr. CHARLES F. MARVIN
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I AM here to tell you something about our present calendar, that is, the Gregorian calendar now in almost universal use throughout the world, and how it should be simplified. Only in Africa, Asia, and some islands of the South Pacific Ocean, primitive forms of ancient tribal and old national calendars are still in local use, often side by side with the Gregorian calendar. Conflicting differences between the feast days, holy days, work days, etc., by these different calendars are serious hindrances to the orderly progress of modern trade, business and industry in many cosmopolitan cities of India, China and the Far East. The world is now in need of a simple, uniform calendar that all nations can unite in designing, approving and using.

Nearly every one takes our old calendar as a matter of course, or assumes that it is quite perfect. A few even hold to an idea that it is of divine origin, and therefore that it is sacrilegious to meddle with or undertake to change it. A very brief acquaintance with calendar history, however, shows conclusively that all calendars are wholly man-made institutions and that ours is of purely pagan origin and design. It began with, or before, the founding of Rome. At first it was controlled in its operation by primitive minds who strove to make each month begin with a new moon, and, in addition, to have each spring time season, that is, the date of the equinox, fall about the 25th of March. Starting with Romulus, every effort to harmonize this lunar and equinoctial control met with repeated failure and called for repeated changes over many centuries.

The Emperor Numa, in order to maintain the ideals, added two new months, February to follow December and January to begin the new year. Later the Decemvirs shifted the month of February to its present position and made other changes, so that March would always remain the spring time month. All these efforts failed, and the calendar came into hopeless confusion by the time of the mighty Caesar, who abolished all idea of any moon control on the beginning of the months and gave the great Roman Empire its first nearly perfect calendar, controlled by the sun alone. He instituted the familiar quadrennial leap year rule. However, because this rigid rule of adding one day *every* fourth year added one day too many every 128 years, the date of the spring equinox slowly changed. Its date at the time of the great church Council of Nicea in 325 A. D., was March 21. By 1580 its date had changed to March 11.

The leaders of the Roman Catholic Church, especially, long deplored this slow shift in the date of the vernal equinox, because it involved a conflict with the church rule for fixing the date of Easter. At last Pope Gregory XIII decreed the faulty calendar must be reformed by striking out the 10 leap days added in excess between 325 A. D. and 1582, also that, in future, three century leap years in each 400 years must be non-leap-years. This is our present Gregorian calendar. Nearly 200 years elapsed, before England and its American colonies actually adopted the Gregorian reckoning. This was done in 1752, which was the first year in which New Year's Day throughout England and America fell on January 1. Prior thereto New Year's Day was dated March 25.

Finally, it is important that I tell you briefly how the present seven-day week came to find its place in the old Julian calendar. On the 50th day of the exodus from Egypt of the Israelites under the leadership of Moses, among other notable events in their history they received the fourth commandment, directing them to work six days and keep holy the seventh. This command bound only the Israelites, not the Gentile world. However perfectly the Jews may have observed the Decalogue Sabbath every seventh day since the Exodus, there is not a scrap of valid historical evidence to support the irrational claim made by some religious sects that Sabbaths were observed in unbroken succession, long before the Exodus, back indeed to the very time of the creation of man, whatever that may mean to this enlightened civilization.

Furthermore, prior to the spread of Christianity westward over Europe, the week was not a part of the old Roman, or the Julian, or any other pagan or Gentile calendar. Not until the second and third centuries of the Christian era did the present week-day names begin to find a place in the calendars of Europe. Within that period these day names were then very gradually superposed upon the regular official Roman calendar. Strangely enough, this was brought about unofficially by the unopposed public usage of the seven pagan day names given to the seven days of the Christian week. Finally, the Emperor Constantine made this usage official by his edict of 321 A. D., which sanctioned Sunday as a day of rest.

These indisputable facts of history show that calendars belong to the people. They have been made and *changed* many times by imperial rulers or others in high authority. To-day the people themselves are the rulers and they can change the calendar whenever new conditions of civilization require.

Every change in this Roman calendar made in the past was to remove or overcome one serious defect. Numa, the Decemvirs, Caesar, Gregory, all strove to correct and prevent the incessant shifting of the date of the equinox. To them this was the great and intolerable defect of their calendar. No man in those distant ages was able to conceive how this might be accomplished. It remained for Lillius, the adviser of Gregory, to propose the simple leap year rule which effectually solved this calendar riddle of all those earlier ages.

For the past 20 years and more, Chambers of Commerce, scientific organizations, and many leading minds in all walks of life in many nations have been urging a further simplification of the Gregorian calendar, whose grave defects hinder the progress of social, scientific, economic and even the religious affairs of modern times. These matters have been formally considered by the League of Nations since 1924, and important conclusions were reached in an international conference held during last October, in which representatives from 44 nations participated.

Let us briefly analyze the more serious defects.

The wide fluctuation during different years in the date of Easter from March 22 to April 25, while not strictly a fault of the calendar, has by common consent been made a part of the movement for calendar reform. The fluctuations disturb the regularity of industrial, financial, commercial and judicial activities, including the maintenance of a normal plan of school and university studies. Although this is preeminently a religious question which depends upon the free decision of the Christian churches, nevertheless large sections of the various world population have expressed the almost unanimous desire that the date of Easter and dependent movable feasts be fixed or stabilized. The League conference in October was practically unanimous that the common good calls for the stabilization of the movable feasts and the League will submit the question to the churches for such action as they may decide to take.

There are really only two serious or major defects in the present calendar, both of which may be overcome by very simple changes. The first of these is commonly called lack of fixity, and is well illustrated by this New Year's Day. Today is the first day of the first month of the New Year, but it is Friday, the fifth day of the week. Next year New Year's Day will fall on Sunday, and the year after on Monday. This incessant annual change of day names and dates runs through all the months of the whole year and compels us to look up calendars whenever we wish to know the days and dates of periodical events, like Christmas, the Fourth of July, our anniversaries, and any important public event. This serious calendar defect can be quite overcome if we all agree to a simple change which makes January 1 of each year always a Sunday, for example. All that is required to attain this result is to give a new name, such as Yearday, to the very last day in each ordinary year. Since each non-leap-year begins and ends on a day of the same name it is plain that if the year begins on Sunday and the last day is named Yearday, the name Sunday is available to name the first day of the next year, indefinitely, provided the extra day added in leap years is given a non-week-day name, like Leapday. This simple change easily removes the serious defect of lack of fixity of the present calendar.

The second serious defect is the unequal length of the months, more especially that, with one exception, fractions of weeks now occur at the beginning or at the end of every month. The simple and easy solution of this defect is to make every month contain exactly four weeks, just like February in ordinary years. This requires a calendar of exactly thirteen 28-day months, year day and leap day being the 29th day to two of the months when required.

While no final decision was reached at the League Conference, chiefly because of the disturbed order of things and because the governments themselves have not as yet given the question sufficient study, nevertheless the defects of the calendar were clearly recognized, also that there is no reason for changing our calendar except to remove those defects. Therefore, *little* or *partial* changes advocated by some can not be favored because one or more of the major defects still remain and the *little* change works no real benefit to ourselves or our posterity.

Changing a calendar is a question of reason and common sense applied to a study of the intricate technicalities of the matter. Our sentiments and our conservatism, however, naturally incline us to resent, at first, any proposals for a change. Nevertheless, I hope that many who hear me will favor this important world movement which in this modern age must be attained through the force of public approval rather than by some imperial edict as sufficed in the past.

THE AMPHIBIAN IN ART AND LITERATURE

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IT is evident, from art and literature, that the frog and the toad were well known by the most ancient civilizations of the world. Long before the time of Christ, they were occasionally used in primitive art. The first semblance of an amphibian is an amulet of a toad, belonging to the period S. D. 39,[1] unearthed along the western bank of the Nile in the vicinity of Gezeh (Fig. 1). A Chinese sacrificial vessel of jade in the form of a toad was discovered belonging to the Hsia or Shang dynasties somewhere between 2205 and 1122 B. C. (Fig. 2).

In a sense, it is remarkable that the amphibian motif should be found at such early dates, for they are not common in art, even during later periods. The fish, a near but humbler relative of the frog, appears commonly through all Oriental, European and American art, ancient and modern. On the other hand, fear and sorcery were associated with the frog and toad, and apparently these decorative motifs have been used by the ancients only as charms or on sacrificial vessels. This limited use of amphibian in art may explain the comparative scarcity of such motives.

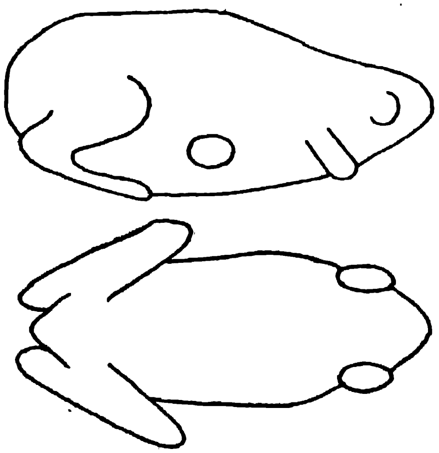

FIG. 1. A STONE AMULET FROM THE BANKS OF THE NILE UNEARTHED ABOUT 3400 B. C. (REDRAWN AFTER CHILDE).

In early Egyptian times, the frog represented the Goddess Heqt (Fig. 3). Her rôle is rather vague, but it is supposed that she was associated with the idea of resurrection. She was the guardian of the mother and the newborn infant and was emblematic of renewed birth. In contrast, the Scarabaeus, or sacred beetle, symbolized duration of life on earth and in the after world and is one of the commonest motifs in ancient Egyptian art. The amulet (Fig. 1) was worn on a string by mothers as a charm (a charm in the true sense, to avert evil or insure good fortune). The frog symbol has been carried even into Christian times. Lamps, probably of Roman origin, have been found in Egypt in which the toad was used as an ornament on the top. These are covered with hard green glaze, much crackled,

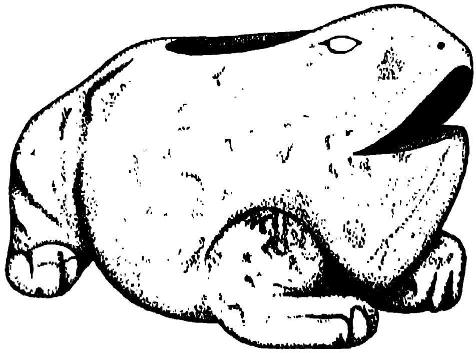

FIG. 2. A JADE SACRIFICIAL VESSEL FROM CHINA OF THE HSIA OF SHANG DYNASTY BETWEEN 2205 AND 1122 B. C. (AFTER HOBSON).

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[1] Sequence dates of Sir Flanders Petrie, more than 3400 B. C.

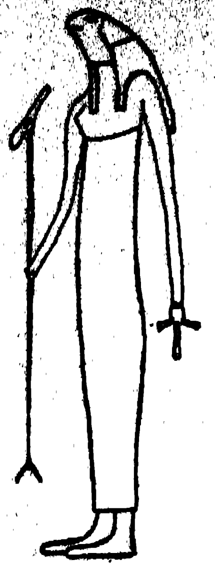


FIG. 3. THE FROG-HEADED GODDESS HEQT (AFTER BRODRICK).

and present a singular resemblance to Chinese enamel ware. Several lamps of this sort have been found in bright red pottery.

Of the Oriental races, the Chinese and Japanese have used the frog and toad most in decorative art. An astrological three-legged toad (Siam-ee) of China is supposed to represent the spirit that looks after one of the places of the moon. When houses stand in a position so as not to get the full influence of the moon, this animal is painted on the house in some conspicuous spot. The toad is also regarded as endowed with sinister qualities and has the reputation of breathing forth poisonous vapors. During the first and second centuries of the Christian era, the Chinese and Japanese artist usually figured the toad on panels or screens in floral patterns. The toad is the attribute of Taoist rishi (Gama Sennin) and is frequently figured with Gama Sennin breathing forth poisonous fumes. The most popular legend represented in Japanese art is Ono no Tōfū. Ono no Tōfū learned the lesson of patience by observing the frog and he is frequently figured gazing at a frog.

During later centuries, the frog is represented in various ways in Europe. German jewelry of the fourteenth and fifteenth century occasionally bears the images of frogs. Labarte illustrates a magical gold ring which was worn on the thumb (Fig. 4) and another ring with a toad carved in a stone set in gold. The "Newcastle mug" of the eighteenth century in England is notable, in which a frog was so placed that one drinking saw him emerge as the liquor became low. These mugs were frequently inscribed with rhymes as follows:

Though malt and venom
seem united
Don't break my pot
nor be affrighted.

It is said that a similar custom was practiced by the Chinese, and many cups have been found with frogs on the inside to frighten the drinker.

For those who follow the popular pastime of collecting antiques, a lookout for some of the Wedgwood pottery of the eighteenth century would be profitable. Catherine II of Russia ordered the great master Josiah Wedgwood to decorate a set of 1,200 dishes for use in

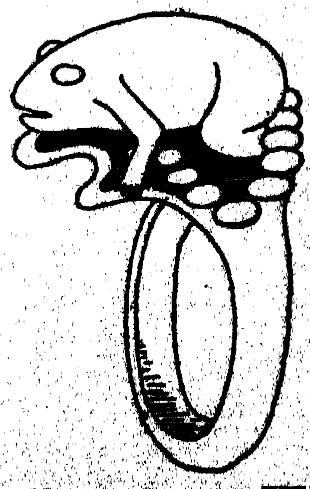


FIG. 4. MAGICAL RING OF THE XIV CENTURY, GERMANY (REDRAWN AFTER LABARTE).

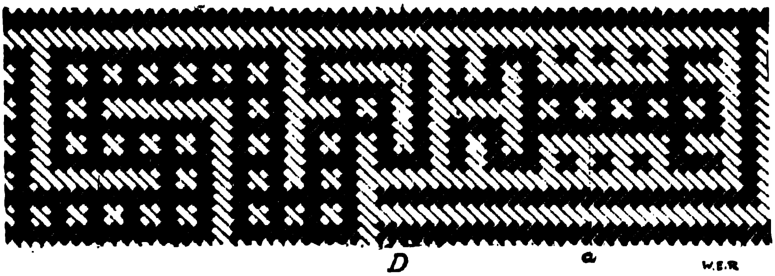


Fig. 5. A snake about to swallow a frog, from a basket of the Guiana Indians (after Roth).

her country place, which she called "La Grenouillere" (frog's manor) because it was situated in a frog-haunted marsh land. Early in the nineteenth century, nine hundred of the original pieces of the set were rediscovered in St. Petersburg. It is believed that during the Russian Revolution every piece disappeared. The decoration is a simple purplish brown on a cream background, with a green frog in a shield. These pieces have been turning up individually in European shops.

Among the American Indians, a few rare bits of pottery, basketry, beadwork and ornaments have been discovered bearing the images of frogs. Roth, in "Animism and Folk Lore of the Guiana Indians" shows that the frog and toad have been used extensively in their arts and myths. A beautiful piece of basketry work (Fig. 5) shows a snake about to eat a frog and may represent the idea that the frog is feared and should be exterminated. He figures modern whistles and rattles, in the shape of frogs, ancient stools and benches, with grotesque figures of frogs, and glass bead aprons, bearing frog patterns. The glass bead apron, worn by the Guiana woman, bears a design, supposedly the legs of a frog, which suggests its use as a charm.

A piece of pottery, which he figures but does not discuss, apparently has a handle in the form of a frog. Fewkes, in "A Prehistoric Island Culture Area of America," illustrates an excellent polished stone amulet in the form of a frog, the workmanship of a race that perfected the polishing of stone (Fig. 6). The frog motif has been used sparingly by the Peruvians, according to Mead, but never in the conventionalized form. The Colombians represented the frog peeping over the rims of their jugs. The Cheyennes frequently figured frogs as well as turtles, otters and other aquatic animals on their drinking cups. The Hopi used the immature frog (tadpole) as a decoration on pottery (Fig. 7). Another piece of Hopi pottery shows a combination of clouds and tadpoles, possibly a graphic representation of the ancient idea that it sometimes "rains frogs." One of the most beautiful pieces of work is a jet and turquoise inlaid charm from the Pueblo Bonito (Fig. 8).

A crude picture of a toad has been found among the rock paintings of the Okanagon.

Through the courtesy of Dr. Frans Bloom, I had the opportunity of studying several amphibian artifacts in the archeological collection at Tulane University. From the Uloa Valley of the Maya country, there is a frog whistle of pottery. The specimen has two openings at the tail end and a single opening on the front right leg on the inside. In the same collection from Mexico, there is a black stone frog, of questionable use,

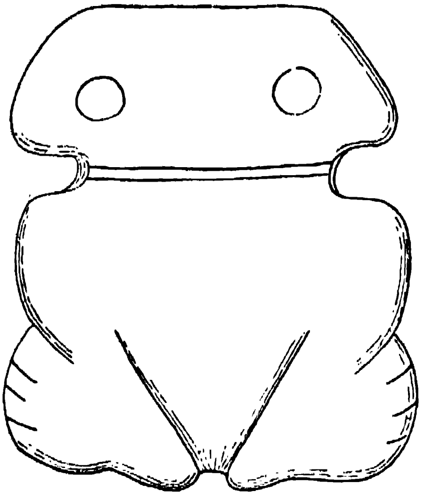


FIG. 6. AN AMULET FROM THE PREHISTORIC CULTURE OF THE WEST INDIES (AFTER FEWKES).

and a brown clay frog, three inches long, with mouth wide open and apparently used as an incense burner. Recent excavations by the Yaxchilian Expedition, conducted by the Carnegie Institution of Washington, revealed a frog on a lintel, representing the final or twenty day period.

Our first written record of frogs is probably the plagues of Egypt, supposed to have occurred about 1451 B. C., written originally in Hebrew but not translated into Greek until about 280 B. C. Aristotle (384–322 B. C.) was the first to mention the habits of these animals. In "Historia Animalum" he describes the croaking of the frogs and the feeding of the toads.

Through the fable, we get some of the earliest fragments of literature dealing with frogs and toads. Aesop (620–560 B. C.) is the author of more than four hundred fables, although it is believed that he did not commit them to writing. The elaboration and translation of these was the task of later fabulists. All contain some essence of truth concerning nature, a moral, and often profound ambiguities. We quote one from the Thomas James translation, Fable 78 Halm., "The Quack Frog." A frog, emerging from the mud of a swamp, proclaimed to all the world that he came to cure all disease. "Here!" he cried, "come and see a doctor, the proprietor of medicines such as man has never heard of before; no, not even Aesculapius himself, Jove's court-physician!" "And how," said the Fox, "dare you set up to heal others, who are not able to cure your own limping gait and blotched wrinkled skin?"

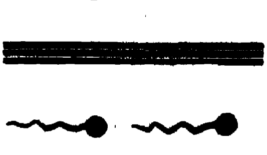


FIG. 7. TADPOLE DESIGN ON PREHISTORIC HOPI POTTERY (AFTER FEWKES).

Aristophanes (448–385 B. C.), the comic dramatist and poet of Athens, contributed "The Frogs," an attempt to distract man's mind from public affairs. It is termed a literary criticism and, like Hogarth, in art, and Addison and Steel, in literature, depicts the evils of the century.

Babrius, a Roman of the third century, has given us over 125 fables, which were probably adapted from the unwritten fables of Aesop. Another Roman, Phaedrus, of the tenth century, translated forty-two fables into Latin elegiacs. One, "The Frogs Asking for a King," has been frequently translated and quoted.

A number of Hindu fables have been preserved, written supposedly by Bidpai in Sanskrit in thirteen parts. These were lost, except a portion called the Panchatrantra, the five books. Some of these have been translated by later writers, especially a collection known as Hitopadesa, which contains several fables dealing with frogs.

In one of the Hindu myths, Agni, the fire god took refuge in the water to escape the wrath of his enemies. He generated much heat, which caused great suffering among the frogs. The frogs became angry, and Agni cursed them so that their speech should henceforth be inarticulate.

Mikhithar Goch, an Armenian fabulist, gives us "The Big Fish and the Frogs."

From the African folk tales of Angola comes "The Frog's Saddle Horse" and from the Bornu "The Rat and the Toad."

Another Oriental myth related that a toad lived in a deep pool exhaling poisonous vapors that caused the death of numerous people that passed by. Lin-He decided to destroy the toad. Its secluded habits prevented its capture until a gold coin was dangled at the end of a hook, which proved the downfall of the toad. This myth is said to be the origin of the proverb, "The glitter of gold lures men to destruction."

A Japanese allegory, in which a snake, a toad and a snail are concerned, is known as San Sukuni, "The three cringing ones." The snake can swallow the toad, the toad can swallow the snail, but the snail in turn can destroy the snake by covering it with a slimy excretion.

Coming to more recent times, Robert Dodsley (1703–1764), an English writer, and Thomas de Irate (1750–1791), a Spanish author, have written fables resembling those of earlier fabulists, many of them concerning frogs and toads.

Famous naturalists, as Carl von Linneaeus (1707–1778) and Thomas Belt (1832–1878), have frequently written about these animals. Belt describes, in unusual language, one of the frogs in the woods of Santo Domingo, "Dressed in bright livery red, his flaming vest and blue stockings."

The only serious attempt at the frog in modern literature, scientific articles excluded, is "The Celebrated Jumping Frogs of Calaveras County," by S. L. Clemens, which was first published in a newspaper and later gained literary fame.

There are evidences that the toad and the frog were well known by the American Indians, although they were seldom used in art. We know of two tribes of the Creek Indians of Oklahoma and Alabama that had toad clans by the names Sopaktalgi and Sanaktcali, respectively. The language of many tribes show a first-hand knowledge of the toad. The Mohawks have a word "Jighantak," the Cayugas a word "Naskwanaonta" and the Tuscaroras a word "Roo-nunk-shwah," to denote the toad.

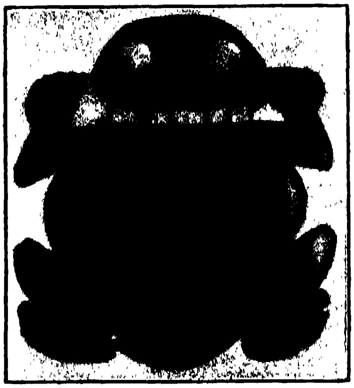


FIG. 8. A BEAUTIFUL JET AND TURQUOIS INLAY FROM THE PUEBLO BONITO (AFTER WISSLER).

Myths lend many valuable accounts of the habits and beliefs of our Indians and give us an idea of the use and estimation of the toad and frog. An Iroquoian myth is related by Converse, "How the flying squirrel won his wings, the frog lost its teeth and the woodchuck its appetite." This is a beautiful tale and equally as instructive as any of the fables or stories written for children. A squirrel had laid away his winter's supply of nuts, but they had been mysteriously disappearing. Nukdago, the chief of the squirrel tribe, decided to find out who was the thief. At midnight he entered the forest on a tour of inspection and found a woodchuck busy carrying the nuts away as fast as he could. The next day, Nukdago continued to watch and saw a frog taking nuts and hiding them beneath some moss. Nukdago called a council of all the chiefs of the forest clans. Turning to the frog, he accused him of selfishness and theft, reminding him that he slept all winter and had no excuse to rob his neighbor. As punishment, he decreed that the frog tribe would no longer have teeth and could not eat nuts again. Turning to the woodchuck, he likewise accused him of selfishness and theft, reminding him that he too slept all winter and had no reason to rob his neighbor. As punishment, he decreed that the woodchuck tribe could no longer relish beaver or fish, but must eat grains. He commanded him to go back in disgrace and not return until the spring painted his shadow on the snow. Nukdago rewarded the squirrel by giving him wings so that he could fly back and guard his nest.

We are fortunate in having extensive accounts of the Tlingit myths by Swanton, and the Tsimshian myths by Boas. An old Tlingit myth relates how a woman lived with a frog. This story is not unusual, as Indian myths are replete with accounts of the relationship of woman in matrimonial affiliations with various animals. No doubt the frog represented a very low form of degradation. A Tsimshian myth tells of a boy that caught a great frog. A chief's nephew was a poor orphan. One day a white bear was heard near the village and the chief promised his daughter to him who killed the beast. The orphan boy killed it, but other boys claimed the honor. The orphan boy's arrow was found, and the chief, being very much ashamed, left his nephew, daughter and grandmother. The orphan went to a pond and shouted and a great frog emerged and pursued him. He made a big trap and caught the frog. He skinned the frog and with its charm was able to catch very many fish. A princess learned of this and married him. About this time, the chief's people were starving, and he sent a slave to find out whether his nephew, daughter and grandmother were still alive. The boy sent back food for his uncle. He continued to catch fish, which he sold to buy slaves and eventually he became a chief. This continued, but he was unable to throw off his frog blanket and he stayed in the pond where he provided food for his family.

The Indians used frogs chiefly in sorcery, although a few tribes used them as food. Boas, in treating of the ethnology of the Kwakiutl, states that the feet of a toad, together with four arms of an octopus and the tip of the tail of a snake, were used as a charm at childbirth. The Kwakiutls had their frog dances, frog songs and frog whistles. The Creek Indians also had a frog dance known as Akatalaswa obanga. The Akatalaswa was a very small but a very noisy frog. Roth, in "Animism and Folk Lore of the Guiana Indians," dwells upon the uses of the frog and toad for augury. They foretold rain, brought fire and wood and assisted in hunting. They were used in ordeals and as charms. Hunting and music were taught by them and they were eaten as food. Among the numerous string tricks, used in ceremonials, one was called the frog. The Salishan tribes of the Western Plains believed that killing frogs brought rain. Their women used the toad to poison their husbands. A large black toad was hung to the branches of a tree by the legs. The mouth was propped open by means of a stick and the juices allowed to fall into a vessel. Sometimes the toad was placed on a flat rock and pounded with a second rock until the toad was dead. Then the juices of the body were collected. In either case the poison was placed on the food to be eaten. The Winnebago, according to Radin, used the toad only for poison medicine.

Recent civilizations have given evidence of their fear, dislike or familiarity of the frog through place names. We have: Froges, France; Frog Lake and Frog Portage, Canada; Frogmere, Louisiana; Frogner, Minnesota; Frogville, Oklahoma, and Toadvine, Alabama.

The frog and toad have likewise been immortalized in plants and animals. They serve as convenient handles or common names for numerous plants as: frog bit, a small rootless plant with floating leaves belonging to the family *Hydrocharitaceae;* frog orchis, Habenaria of England, a relative of our beautiful and somewhat rare purple fringed orchis, also the European Oncidium, so-called frog orchis because its lip bears at its base the figure of a frog, couchant; frog cheese, one of many large puff-balls or mushrooms; frog flower and frogwort, common names for the buttercup; frog fruit, a species of Lippia; frog grass, a species of glasswort, Salicornia; frog-lily, a common yellow lily. Nymphaea; toad lily, an ornamental of Japan of the genus Tricytis; toad orchis, a species of Megaclinium from Sierra Leono; toad pipe, a species of horse tail, Equisetum; toad rush, one of the Juncaceae; toadflax, a weed of the genus Linaria; bastard toadflax, a species of the genus Comandra; toad flower, a species of Stapelia; toadstool, one of the many capped mushrooms; toad mouth, a species of Antirrhinum, also called lion's mouth.

Among the animals we find common names as: frog mouth, an Australian bird, Podargus, so named from its cry; the fishing frog, Lophius, one of the bottom-feeding fishes of the coast of Europe and Western North America; frog hopper, a group of insects also known as spittle insects of the family *Fulgoridae;* frog crab, one of the Raninoid crabs; toad bug, several true bugs of the family *Gelastocoridae;* toad fish, numerous tropical fish, especially of the genus *Batrachus;* toad head, a local name for the golden plover.

The words frog and toad are also used in the English language to denote other things or ideas, as the frog of a railway or toady from toadied, meaning to frown upon.

The frog and the toad have inspired a few poets. Geoffroy Chaucer mentions the frog briefly in two lines:

> In places sawe I welles there,
> In whych there no frogges were.

John Burroughs' reference to the frog is scarcely more pleasing:

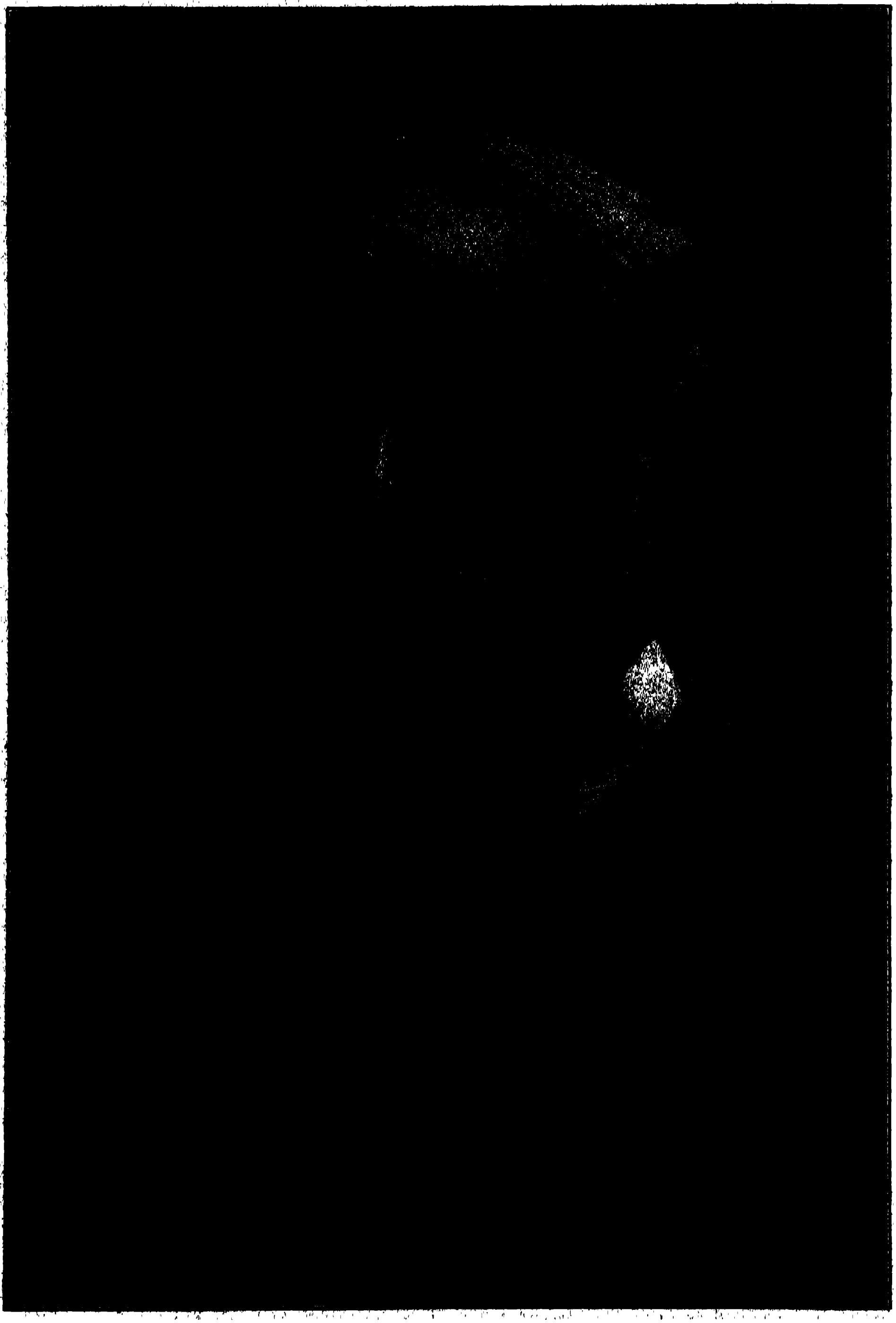
> I believe a leaf of grass is no less than the journey-work of the stars,
> And the pismere is equally perfect and a grain of sand and the eggs of the wren
> And the tree toad is chef-d'oeuvre for the highest.

From John Greenleaf Whittier's "Barefoot Boy" comes the following pleasing lines:

> While for music came the play
> of the pied frog's orchestra
> And to light the noisy choir
> Lit the fly the lamps of fire.

A number of other poets have written about the toad and the frog, especially: Anne Bradstreet, "The Four Seasons of the Year"; Juliana Horatia Ewing, "A Friend of the Garden," concerning the toad; Thomas Westwood, "Tourncoats," and one by an English author, Hilaire Belloc. In closing we quote from James Whitcomb Riley:

> Who am I but The Frog.—The Frog!
> My realm is the dark bayou,
> And my throne is the muddy and moss-grown log
> That the poison ivy clings to—
> And the black snakes slide in the shining tide
> Where the ghost of the moon looks blue.



GENERAL A. W. GREELY

THE DISTINGUISHED ARCTIC EXPLORER AND METEOROLOGIST WHO CELEBRATES HIS EIGHTY-EIGHTH BIRTHDAY ON MARCH 27.

THE PROGRESS OF SCIENCE

AWARD OF THE AGASSIZ MEDAL TO DR. BIGELOW

PROFESSOR HENRY BRYANT BIGELOW, who received the Agassiz Oceanographic Medal at the November meeting of the National Academy of Sciences held at Yale University, was born in Boston on October 3, 1879. He was trained at the Harvard Laboratories and took his doctor's degree there in 1906. His publications, all of which refer in one way or another to oceanographic subjects, total over half a hundred.

His first paper, entitled "Birds of the Northeast Coast of Labrador," appeared in 1902. In the winter of 1901–02, he accompanied Mr. Alexander Agassiz on a voyage to the Maldive Islands, and in 1904 he published his report on the jelly-fishes of this expedition. In 1904–05, he again accompanied Mr. Agassiz this time on the expedition to the Eastern Tropical Pacific and in 1909, he published his very extensive report on the Medusae of this expedition and two years later the report on the Siphonophores.

Meanwhile, through the advice of Sir John Murray, he began to take an active interest in the oceanography of the New England waters. In 1908, the U. S. Fisheries schooner, *Grampus* was sent under his general management on an expedition to the Gulf Stream, a report of which he published in 1909. This initiated his extensive series of studies of the waters of the Gulf of Maine. These were made possible largely through cooperation with the U. S. Bureau of Fisheries, which repeatedly put at his disposal the use of the *Grampus*. In 1914, he reported on the oceanography of this region, and in the same year he published an account of the plankton of Massachusetts Bay. This was followed by a report on the oceanography and plankton of the waters between Nova Scotia and Chesapeake Bay. In 1917 an additional report was made on the region from Cape Cod to Halifax. Then followed the three extensive contributions of 1926 and 1927 covering the plankton of the Gulf of Maine, its dynamic oceanography and its physical oceanography. Meanwhile, in conjunction with William Welsh, he had issued his important volume on the fishes of this region. The proposal for an ice patrol as a means of greater security for shipping in the North Atlantic had been taken up by the U. S. Government, and, in association with Lieutenant Smith, Bigelow worked out much of the details of this organization. A report on this subject was published in 1929.

As work progressed the conviction grew upon him that an oceanographic institution should be started on the Atlantic coast of the United States, and he reported on this subject to the National Academy of Sciences in 1930. The material of this report was finally issued in the form of a volume entitled "Oceanography, its Scope, Problems, and Economic Importance." This volume was published in 1931 and was distributed to the members of the academy. As a result of these activities the Woods Hole Oceanographic Institution was organized and a building to house it was erected near the Marine Biological Laboratory at Woods Hole and opened this past summer. Dr. Bigelow has served as its first director.

Dr. Bigelow during his student days was not reputed as a diligent scholar. In fact, he was informed by one of his old teachers that he would do well to withdraw from the Harvard Laboratories, for he was judged both negligent

DR. ANNIE JUMP CANNON

and idle. Bigelow, however, had his own way of working and has demonstrated that these ways lead to affective results. He is soaked with the atmosphere of the sea and will unquestionably devote himself to the end of his days to the promotion of oceanography.

As a life-long associate of Alexander Agassiz and as a close personal friend of Sir John Murray, his appointment as an Agassiz medalist is especially appropriate, but the real ground for the presentation of the Agassiz Medal to him is his position as one of the first oceanographers of the world.

G. H. P.

THE AWARD OF THE DRAPER MEDAL TO DR. ANNIE J. CANNON

One of the most marked distinctions in the American astronomical world was recently conferred on Dr. Annie Jump Cannon, of the Harvard College Observatory at a meeting of the National Academy of Sciences in New Haven last November, when she was awarded the Henry Draper Medal for outstanding achievement in astronomical physics.

Perhaps no single item of information about the stars finds its way into so many different aspects of astronomical research as does the knowledge of their spectra. In problems of distance, brightness, temperature, size, motions, distribution in space, variation, and physical structure, the spectrum of a star plays a revealing rôle. And it is to Miss Cannon's untiring work during the past thirty years that much of the present knowledge of stellar spectra owes its existence.

Dr. Cannon, who was born in Dover, Delaware, graduated from Wellesley College. She has received honorary degrees from Wellesley, from Groningen and from Oxford, where she was the first woman to receive the honorary degree of Doctor of Science.

The work which was, in the course of time, to provide such a powerful instrument for astronomers in their analysis of stellar structure, was begun at the instigation of Professor Pickering, then director of the Harvard Observatory. A considerable amount of work had been done on classifying spectra on the Harvard photographs. Miss Cannon reorganized the classification, and so effective was the result that it has, with few additions, remained ever since the internationally accepted basis for stellar analysis.

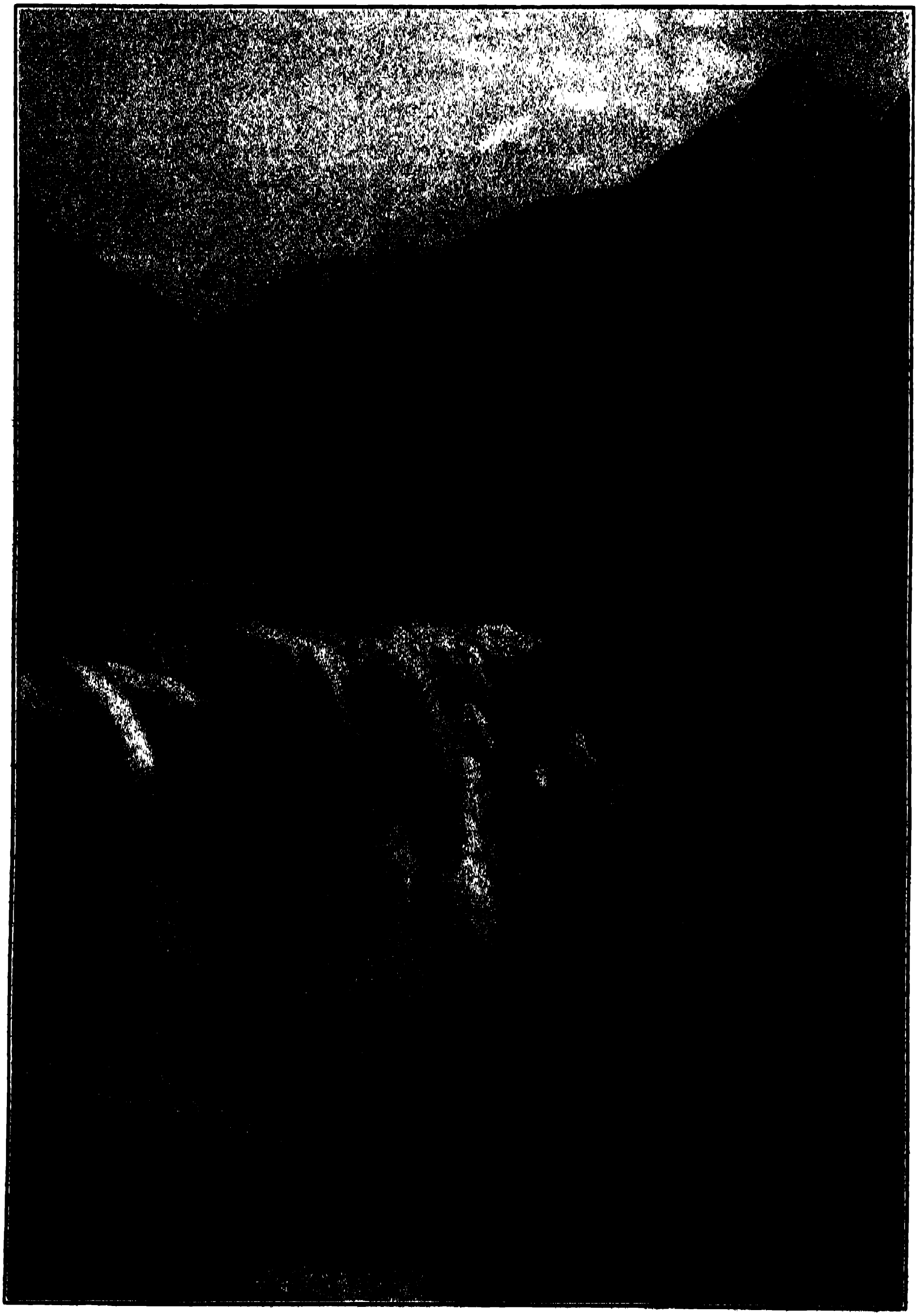
The most distinguishing characteristic of Miss Cannon's classification of stars is the fact that it reveals a continuous sequence throughout the entire gamut of stellar types. This relationship exhibited among all classes of stars shows the possibility of an evolutionary progress, and offers much in the way of explaining the history and development of the stars.

During a period of fifteen years Miss Cannon devoted her energies to analyzing and classifying 225,000 stars, over the whole sky. Her results were published in a series of nine volumes of the Harvard Observatory Annals, in which are given not only the stars' spectra, but their positions and magnitudes as well.

Since completion of this catalogue, Miss Cannon has demonstrated her remarkable energy and enthusiasm by undertaking an extension to the catalogue, comprising stars of magnitudes fainter than those earlier classified. This extension already contains the classification of over a hundred thousand stars.

The catalogue is itself a memorial to Henry Draper. It is peculiarly fitting that the valuable work of Dr. Cannon should be acknowledged by the conferring on her of the Henry Draper Medal.

J. M.



THE FALL OF REUSS

FROM THE PFAFFENSPRUNG, ABOUT 900 FEET ABOVE THE POWER WORKS AT AMSTEG.

DEVELOPMENT OF WATER POWER IN SWITZERLAND

SWITZERLAND, land of scenic grandeur, high peaks, rushing mountain torrents and accumulating glaciers, early turned a far-seeing business eye on natural assets for industrial purposes. Centrally located without a seaport, knit in by rugged mountains, without adequate farming facilities, the country was forced to turn its attention to the electrical energy hoarded in water power for economic development.

In the course of the last century the products of the soil became inadequate to provide for the maintenance of an ever-increasing population. Coal was an expensive import, as there are no coal mines in Switzerland. Her rivers and water falls are, however, a great natural wealth and their exploitation for power has become a vital economic factor ever since electrotechnical methods made the utilization of energy possible at a great distance. Not only is electric energy now used almost entirely for the railways and for other industrial and motor purposes, but also 90 per cent. of the Swiss people have electric lighting and 98 per cent. of the municipalities are branched on to an electric system.

The topography of Switzerland facilitates the use of water as power. The total surface measures only about 16,000 square miles, yet in this small area there are tremendous differences of altitude. The highest point, Dufourspitze of Monte Rosa in the Alps, is 15,217 feet above sea-level, while the lowest is 581 feet on the Lago Maggiore. The declivities are consequently very pronounced and the river, stream and torrent beds are abrupt. It is difficult to estimate the available water power of a country, but it has been approximated that Switzerland has available four million horsepower. The United States, with an area almost one hundred and ninety times that of Switzerland, has available only fifty-five million horsepower, or about fourteen times that of Switzerland.

Judging from the above, the prevalent conditions would appear to be favorable and simple. Switzerland's hydrologic régime, however, has a peculiarity which has a strong influence on the country's hydroelectric economy and determines the course to be pursued for the exploitation of water power. Although 60 per cent. of the precipitations occur during the five winter months (November to March) and only 40 per cent. during the seven summer months (April to October), rivers and streams have high waters in summer and low waters in winter. This curious condition results from the high altitude of the Swiss territory, which averages 4,429 feet above sea-level. The Alps are covered with snow and ice throughout the year. During the summer months a portion of the glaciers melts, whereas in winter and autumn precipitations in these regions generally take place in the form of snow and remain stationary. The energy which, in winter, is produced directly without compensation by means of accumulation, constitutes but one third of that obtained during the summer.

Exactly the opposite takes place as regards consumption and demand throughout the year. Demand is greater in winter than in summer for lighting and heating. Although this difference is not as pronounced to-day as it was formerly when electricity was used almost exclusively for lighting purposes, maximum consumption of electric current during a winter day still comes to 120 per cent. of the average daily consumption throughout the year; that for a summer day represents about 80 per cent.

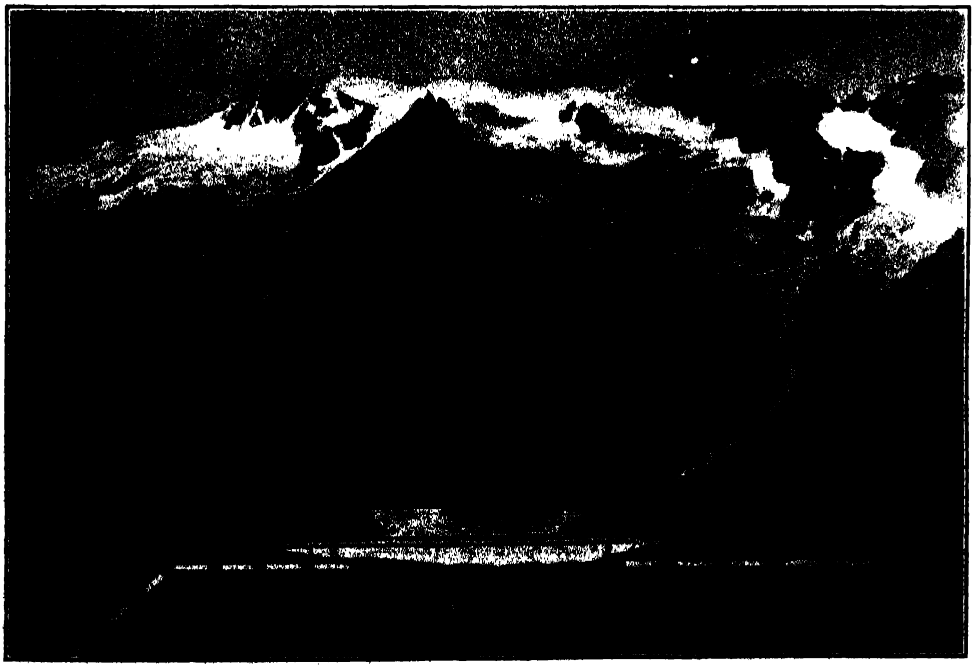
THE BARBERINE RESERVOIR

NEAR CHÂTELARD IN THE VALAIS, A BEAUTIFUL ALPINE RESORT REACHED BY THE ELECTRIC RAILWAY CONNECTING MARTIGNY WITH CHAMONIX.

An economical exploitation of the natural energy of Swiss water-courses is only possible by adopting a measure to compensate the divergency between output and consumption.

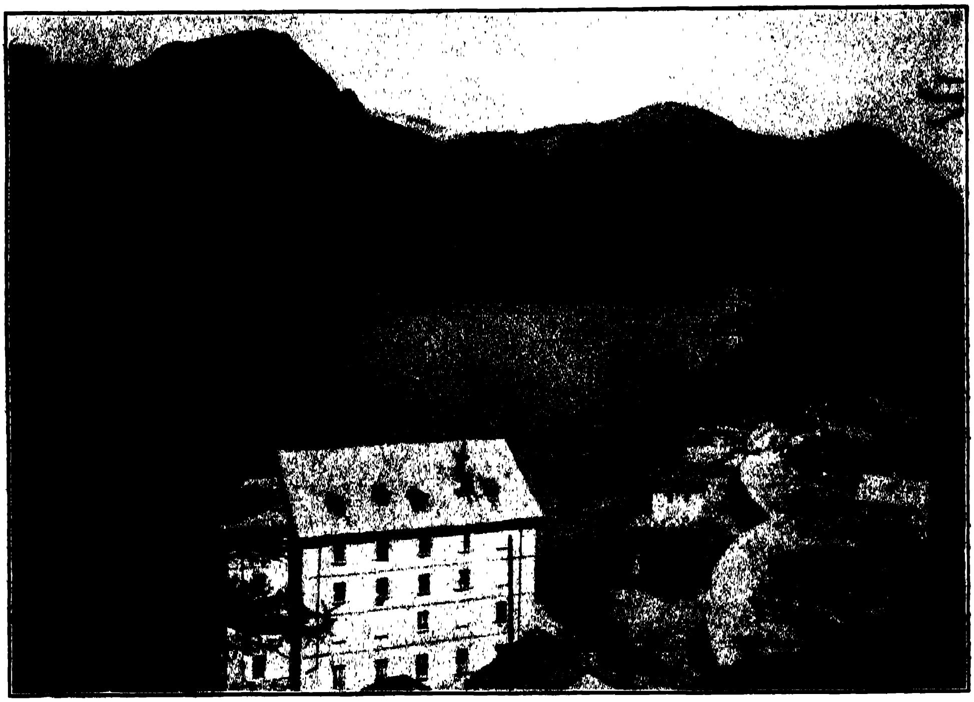
Among the various methods advocated, such as the creation of industries which do not require electricity throughout the year, the construction of thermic plants or the exportation of electric current in summer, the system of hydraulic accumulation of energy during the summer, when output exceeds consumption, is the most economical and popular in Switzerland.

Accumulation is effectuated by means of dams for the retention of the water during the summer. This method is expensive and the many constructions are necessary. To create artificial basins (or to increase the capacity of lakes already in existence) requires the flooding of vast areas. It is, therefore, necessary to select sites where accumulation is possible over as small and inexpensive a territory as possible, preferably waste or uncultivated land; and economy further demands that the accumulated water yield the greatest possible amount of energy per unit (meter^3) in order to diminish the volume of water required per unit of energy (kilowatt), offering thereby a good return for the capital invested in the enterprise. This result is obtained by the construction of plants having basins for accumulation situated on rivers or mountain torrents with powerful falls. The energy produced by a waterfall is proportionate, on one hand, to the volume of water flowing per second, and, on the other, to the height of the fall. The greater the latter, the smaller the volume of water necessary to furnish a given amount of energy.



LAKE GELMER IN THE BERNESE OBERLAND

FORMS PART OF THE HUGE GRIMSEL POWER WORKS WHICH ARE NOW UNDER CONSTRUCTION.



THE RITOM LAKE

SUPPLIES A PORTION OF THE WATER-POWER FOR THE ELECTRIFIED GOTHARD RAILWAY. A FUNICULAR RAILWAY CONNECTS THE POWER STATION AT PIOTTA, SOUTH OF THE GREAT TUNNEL, WITH THIS LAKE.

In Switzerland, electric generating plants are constructed, consequently, in the vicinity of the Alps, where small torrents with powerful falls produce large quantities of electric energy with comparatively little water, this condition reduces the dimensions of basins and dams required and at the same time at such altitudes land is less expensive than elsewhere.

This seasonal variation in output and consumption contributed towards the creation of groups of combined plants. While some plants, situated on the lower portions of rivers or streams, utilize in summer great masses of water with gentle falls to produce considerable quantities of energy, others, in the higher Alpine regions, fill their accumulation basins in preparation for the low-water period. As long as the former are able to cover the demand, the latter are not put into action. At the beginning of winter with its lower water level and increased consumption, these plants are then called upon. The waters accumulated throughout the summer months are slowly utilized, whereas the plants at lower altitudes produce considerably less energy.

Considered from an economic and financial point of view, these groups of power plants are not all organized on the same basis. The Swiss Confederation owns the groups connected with the electric traction of the state railways only. A small number are owned by the cantons or municipalities. Others are run by private companies. The most important groups, however, such as the "Forces Motrices Bernoises," the "Nord-Est Suisse," "l'Energie Ouest

Suisse" and others are owned by "mixed companies," of which the larger portion of the stock is in the hands of the cantons or municipalities. In this case private capital cooperates with public economy in a combination which has given excellent results in the majority of cases, according to Professor C. Andreae, Engineer E.P.F., former rector of the Federal School of Technology at Zurich.

The largest power plant for accumulation in Europe is now under construction on the river Aare at the Grimsel Pass, where much attention is being paid to the architectural possibilities of the plant. Already there are approximately 160 plants equipped with installations capable of producing over 1,000 h.p. and the total capacity of generating stations, at the end of 1927, had increased 151 per cent. over 1914. Now Switzerland, utilizing 1.6 million of the approximate four millions of horsepower available, has come to the place where only Great Britain and Belgium have a relatively greater industrial population.

RUBBER FROM ROCKS

A FEW weeks ago du Pont chemists startled the scientific world by announcing the first commercially successful artificial rubber. While the press promptly reported the achievement, the somewhat meager character of the reports has led many people to view the announcement with skepticism. Such an attitude, however, is not justified. In reality, one of the fondest dreams of the synthetic chemist has at last been realized, and a man-made product, starting from mineral materials totally unrelated to natural rubber, will soon be available at a price which will allow it to compete for certain specialized uses even at the present low price of the natural product.

Numberless attempts have been made in the past to synthesize rubber or to produce some substitute for it. "Cut and try" methods resulted in weird combinations of gelatine, glue, drying oils, ground cork, fish eggs and dung. While some of these messes had resilient and spongy properties, none of them approached the qualities of long wear, elasticity and strength manifest in natural rubber. On the other hand, more scientific methods of approach slowly unraveled the physical and chemical secrets of rubber. Scientists definitely established that the basic constituent of rubber is the simple compound isoprene. Still they could not commercially synthesize rubber. The preparation of isoprene itself is difficult and expensive, and the step from this clear, water-white liquid to rubber is one so difficult that, after years of research, it can be accomplished only very imperfectly. Although Germany, during the last months of the war, used a similar process to produce an inferior material that could be substituted for rubber, necessity in this case dictated disregard of cost and the acceptance of a low-grade material. However, following the war, when the price of raw rubber soared, these processes were not even considered as possible sources of supply.

Despite these failures, when Father Nieuwland, of the University of Notre Dame, several years ago obtained from acetylene traces of a material remotely related to the basic constituent of rubber, du Pont chemists saw in his discovery a possibility of obtaining the long-sought goal. Cooperative study of the problem was arranged and, as a result of this joint enterprise, lasting over several years of disappointing failures, the problem was finally unexpectedly solved. This work has been carried on with the utmost secrecy, and the announcement that synthetic rubber, differing from the natural product in composition, had not only been discovered but was actually being made on a sizable scale came like a bombshell.

Naturally the details of the process are still secret, but we are able to say that the basic materials are limestone, coke and ordinary salt. Thus the new product is entirely independent of living matter for any portion of its source of supply, and is made from cheap and abundant mineral raw materials.

Economically, the du Pont chemists believe that their product will not as yet serve as a substitute for rubber in all uses, but though it is more expensive than rubber at present prices, it is far cheaper than rubber has often been. The important point is that for many uses the new product is superior to rubber. For example, samples soaked in gasoline for days did not swell or deteriorate unduly. Another important advantage is that the new material cures without the addition of sulfur or other foreign bodies to aid in vulcanization. While the investigators conservatively admit that in some respects their material is inferior to the natural product, others minimize these differences. The new material, called "Duprene," is identical with rubber in respect to appearance, feel and stretch, but differs from it in that it has none of the characteristic rubber odor.

While it is of course too early to say with any degree of certainty what effect this new synthetic rubber will have on the production of the natural product, it may be pointed out that the raw materials are cheap and available in many parts of the world. In particular, the United States is freed by it from dependence on outside sources for its rubber. While admittedly the new product is now more expensive than natural rubber, it should be remembered that the process for making it is in its infancy, and with refinements, the price will undoubtedly become more and more competitive. Furthermore, the discovery of synthetic alizarine and of synthetic indigo years ago led ultimately to the practical abandonment of the growing of the madder plant and of natural indigo. Is a similar fate in store for the growing of natural rubber?

Gustavus J. Esselen

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THE UNCERTAINTY PRINCIPLE IN MODERN PHYSICS[1]

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IN the course of the last twenty years there has grown up a great body of doctrine, the quantum theory, and its history is in some ways the most curious in the whole of science. The developments of our knowledge have often progressed in an uneven and irregular manner, with important ideas sometimes long overdue before they appear, but at least the progression is usually based on rational assumptions. With the quantum theory this was not so; from its very inception it seemed to run contrary to all logic. Many conservative physicists at first frankly thought that such a self-contradictory theory must be erroneous, but, as more and more phenomena were accommodated, it became impossible to doubt but that there was method in the quantum's madness, and it was possible to anticipate that some time a new synthesis would be made which would remove the contradictions and restore our reason to us. In 1925 the new synthesis was found, and this independently in two quite separate ways. As would be expected, at first the new theory was very abstract; it was, in fact, by denying the validity of the ordinary laws of multiplication that Heisenberg first brought logic into the old confusion, but it was only a couple of years later that Heisenberg himself showed how these rather formal methods would fit into our ordinary processes of thoughts in a natural way. It is with this aspect of the question that I shall be concerned, and in explaining it I shall make more use of the second resolution of the difficulties of the old quantum theory, which was started by de Broglie and worked out by Schrödinger. A great deal of what I shall be saying is to be attributed to Bohr, who more than any other has cleared up the difficulties in which the old theory was involved.

It is evidently out of the question for me to expound all the difficulties of the old quantum theory and then to set them right—to do so would take many weeks. I propose instead to select two experiments, which between them typify the apparent contradictions of the theory, and then to show how the new principle, the Uncertainty Principle, removes the apparent contradictions. My experiments are to be regarded as types, each standing for a great mass of knowledge, and the reconciliation of them carries with it the removal of the main difficulties in the way of our understanding of the quantum theory.

My first experiment is simple, and in one form or another has been done again and again during the last thirty-five years. Take an evacuated tube arranged to carry an electric discharge between a pair of terminals. Cover one part of the glass inside with some powder of a mineral called willemite, and observe what happens in the dark. We should see that the willemite emits faint sparks at intervals all over its surface. A more detailed study shows that each of the sparks is caused by the impact of an electron. An electron is a particle of electricity and is the lightest thing known; it was by experiments of this type that its characteristics, mass and electric charge, were measured. Moreover, the speed of the electrons could be measured in a variety of ways; in some of the experiments it was done by opening and shutting two holes through which the electrons must pass in succession, and timing how long they took between them. To give a general idea of the speed, it is found that when there are 30,000 volts on the tube (not at all a high voltage) the speed is one third of the speed of light. This experiment tells us quite unambiguously that an electric discharge is like a machine-gun firing bullets, the electrons, at a target.

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[1] Friday evening discourse given at the Royal Institution of Great Britain on February 26.

Now turn to the second experiment. I ought, perhaps, to begin by confessing that this experiment has never been done; as I describe it, you will see why it is not practically possible to do it. It is to be regarded as a type-experiment, containing the essential point of other experiments which are practical, such as the great experiment of Davisson, which first established the point I am about to explain. We shall again study an electric discharge of 30,000 volts in a vacuum, but this time with a different outfit inside. We place a shutter in the track of the electrons, containing two small holes in it close together. This is where the practical difficulty comes in, for the two holes are each to be only a thousand millionth of a centimeter in diameter, and they are to be a hundred millionth of a centimeter apart. The tube itself is to be a meter long, and at the end of it, beyond the shutter, we place a photographic plate of extreme sensitivity. After a long exposure (probably centuries would be necessary) we develop the plate. If all this were practically possible there is no doubt what we should observe. The plate would be crossed by alternate bands where it was fogged by the electrons, and bands in between where it was blank, showing that no electrons came there. The bands would be about 7 cms. apart. This is the first half of the experiment. Now repeat it again, but this time with one of the two little holes blocked up. When this plate is developed, we shall find no bands at all, but a uniform fogging all over the plate. Now this is an extremely remarkable fact, when we try to understand how it could come about. Consider one of the blank places on the plate in the first part of the experiment. No electrons came there, and we might try and explain this by saying that in some way the place was protected from the electrons by the shutter. But block up one hole and the place is no longer protected. The addition of what ought obviously to be a further protection has, in fact, had the opposite effect. It is as though the victim of a detective story were invulnerable when sitting in his chair, no matter how many assassins are shooting into the room, as long as he keeps both windows uncurtained, but as soon as the blinds are drawn on one window he falls a victim to the next bullet. This is, of course, fantastic, but it is not more fantastic than my two experiments appear to be at first sight.

As I have stated it, this result seems very remarkable, yet it is a phenomenon quite familiar to any one who has studied physics. It is cognate to one of the great classical experiments of history, the experiment of Thomas Young with light. Young sent light through two small holes close together (though of course by no means so small or close together as those of our experiment), and observed the actual formation of bands, in much the way I described. He deduced from this that light must be a wave motion, and we must turn aside now to consider what this means.

It will suffice for us to take an example, and the most familiar of all will do, that of waves travelling on the surface of the sea. Imagine that we have a perfectly regular train of waves, crest following crest at regular intervals, advancing across the sea towards a breakwater. First, suppose that there is a small gap in the breakwater, and consider what will happen on the other side. Evidently there will emerge from the gap a train of semicircular waves, with crests all at the same distance apart as before. Next, suppose that we have two gaps in the wall not very far apart. To see what happens I will invoke a very fundamental principle in all wave motions, the principle of superposition, which declares that if there are two motions either of which could happen by itself, then there is a third possible motion of the water, which is simply the sum of the other two; each motion goes on just as though the other were not there. In our case, then, semicircular waves will emerge from each gap, and these are to be superposed. It can be seen that at some places they reinforce one another, but at others they cancel out. This is the phenomenon of interference, and is the explanation of Young's experiment with light.

Our experiment with the electrons has told us that electrons also can show interference, and we conclude that an electron is at any rate sometimes a wave. It is a natural question to ask what sort of wave it may be; for example, the waves we have discussed were waves of the surface of water, sound waves are waves of compression of air, and so on. The answer can best be made by considering the case of light waves. It was natural for Young and the physicists of his time to ask what sort of medium carried the light waves of which he had established the existence, and a special name, the ether, was invented for this medium. But things are not helped on a great deal by the use of this name, since there is one essential difference between the ether and the media carrying sound waves, etc. We can do experiments with water or air which show us that they have properties unconnected with the waves they sometimes carry, but the only property of the ether is that it carries the waves of light. Consequently it is not much use talking about it except in connection with conveyance of waves, and so it becomes really a grammatical construction rather than a physical entity. The same is true for our electron waves, and, in fact, no one has felt the need of a name for the medium carrying them.

We have now got from our two experiments two very different pictures of the electron, in the first as a bullet, and in the second as a wave motion. We cannot see any resemblance between these pictures, and it is our chief aim to-day to see how they can be reconciled. One attempt at reconciliation has been tried several times, but must be condemned altogether. If the electron is sometimes like a piece of grit and sometimes like a stormy sea, the natural compromise is to say that it is really a piece of grit floating in a stormy sea. This is no use at all; like many other compromises it enjoys all the disadvantages of both sides. It is not something in the sea that we need, it is the wave motion of the sea itself.

In order to see how we must proceed, we will first strengthen the contrast by uniting our two experiments into one. In order to do this we replace the photographic plate of the second experiment by a willemite screen. We should then observe that there were scintillations in the places where the photographic plate was blackened, but none at all in the blank spaces. We can describe what has happened shortly by saying that the electron behaved like a wave in going through the two holes, but changed over into being a bullet when it reached the screen. This is a very unsatisfactory account of the matter, because it attributes foresight to the electron as to what is expected of it, and if we are fanciful we can imagine that we could swindle the electron by painting the two holes so as to look like a willemite screen, and so cause it to be a particle when it ought to be a wave, and absurdities of that kind.

The answer to these contradictions was found by Bohr. It consists in recognizing that experiments that evoke wave characters and those that evoke particle characters are always mutually exclusive, so that the contradictions do not exist in fact; we can not ever deceive the electron by making the two holes look like willemite. For take our experiment with the two holes; this experiment verifies the electron's wave character. We will try to test whether the electrons were particles at the same time, and the best way of doing this would be to decide which of the two holes each single electron went through. To do this we put thin films over the holes, each lightly powdered with willemite; then when an electron goes through a hole there will be a scintillation there, and in this way we can decide through which hole each electron went. We have thus verified the particle character of the electron, and so we now go round behind the screen to verify that the wave character is still all right, but when we do this we are distressed to find that there is no trace of the bands on the plate. A little thought, however, shows that this is natural, for the flashing of the willemite on the hole will certainly cause a reaction on the electron, altering its speed a little (or perhaps only its phase), and this is enough to spoil all chance of interference. Any experiment devised to show the particle character automatically debars us from verifying at the same time the wave character, and *vice versa.* The real point of Bohr's argument is that we now see that this is not a highly abstract doctrine, but almost a matter of plain common sense.

We have got to convince ourselves that the example cited is not exceptional, and that there is no case where we should find a conflict between the demands of the electron that it is to be either a wave or a particle according to the experiment to which it is submitted. But it will be best for the moment to assume this and to construct a view of nature which will enable us to think about the way things behave. The best view, I think one might say the only view, that one can adopt is that there is in nature a fundamental duality, typified by the characters of wave and particle. An electron, and, in fact, any other piece of matter too, is a wave and a particle, and both characters must be kept in mind, but they must not be mixed. Some experiments evoke the particle characteristics, such as striking the willemite, and others the wave character; and whichever type of experiment is carried out it is this experiment that brings into prominence the corresponding character. We shall have to see later how it is possible that there is no contradiction in such ideas, but first we had better examine the nature of the duality itself, for it is something quite new in scientific thought. I think it should be admitted frankly that we were all quite happy before the duality was discovered, and that it would have been a simpler world if it had turned out that we did not need it, but there it is as the only way in which one can understand the fundamental difficulties of atomic theory. There is nothing like this duality anywhere else in science, but it may perhaps make it more acceptable if I recall that there is a duality in metaphysics which we all accept cheerfully and without complaint. I refer to the duality between the objective and the subjective, between, for example, the rather difficult abstractions of the scientific conception of heat and the much more poignant ideas we have when we burn a finger. Or, again, there is a very complete separation between the idea of light of wave-length, one-twenty-thousandth of a centimeter, and the perception of green light, and yet the one always causes the other. There is the same sort of interdependence, associated with the use of two entirely different languages, in the particle and wave aspects of the electron. It should, perhaps, be confessed that the analogy which I have drawn is not a close one, for the conceptions of metaphysics are not comparable to those of science, but nevertheless it is perhaps helpful as showing how completely and spontaneously we accept, and can not help accepting, one duality, and so perhaps it may mitigate our difficulty in accepting another.

We must now see how the characters of wave and particle are to be associated with one another. The main character of a wave is the wave-length, the distance between successive crests. On the other hand, the main characters of a particle are its speed and position. There is a very simple relation between the speed of the particle aspect and the wave-length of the wave aspect; they are inversely proportional, so that the slower the electron the longer the wave-length. For our 30,000 volt electrons the wave-length, as calculated from the breadth of the fringes, will be very small, less than a thousand-millionth of a centimeter. This is for electrons with speed a third that of light, and it is mostly with these high speeds that the theory has been tested, since only so have the electrons enough energy to fog the plate or produce scintillations. But if we have much slower electrons we get longer wave-lengths; for example, an electron going at the rather slow rate of 1 cm. a second has wave-length about 7 cms.

This is the formal relationship, and I am not, of course, asserting that one could see a wave with crests 7 cms. apart under any conditions. What is asserted is that one would find an exact geometrical similarity between our experiment of the two holes and an experiment with ripples 7 cms. long on the surface of water; if these went through two gaps at the same distance apart the disturbed regions would be found at the same positions as those where the electrons appear. But now let us take our connections of the two aspects more literally. A wave of 7 cms. wave-length does not by any means imply two crests 7 cms. apart; it means a regular train of waves with crests spaced at 7 cms. intervals stretching to infinity in both directions. We have seen that such a wave system corresponds to a particle moving at a rate of 1 cm. a second, but that gives no information at all about what is the most natural and reasonable question that we may ask—where in all this wide sea is the particle? It was the finding of the answer to this question that cleared the whole business up. The answer is that it may be absolutely anywhere. This was quite unforeseen, and seems at first sight contrary to common sense—for, after all, the electron must be somewhere, and there ought to be something corresponding to this fact in the wave aspect. It is the fact that it does make sense that is the point of the uncertainty principle.

To understand it, let us take a slightly different case, since a wave motion stretching to infinity is rather overwhelming.

Take the case of a "wave packet" composed of a number of crests at equal intervals, surrounded by quiet water. If this represents an electron wave, where is the electron-particle? The answer is that though we can not say where it is, we can say where it is not, for it can not be in the undisturbed region outside the packet; if the idea of waves is to mean anything, we must at least suppose that where there is no wave disturbance there can be nothing happening, and so no particle. We must next make a digression to consider how such a wave packet will behave with the lapse of time; this is a well-known and much-studied question of wave motions in general. It is found that a patch of waves travels along in a straight line at a definite rate depending on the wave-length, but that as it goes it spreads so as to increase slowly in size. The rate at which it spreads depends on the length of the packet; a long packet, containing many crests, will only spread slowly, while if it only has a few its spread is very rapid. For our electron we are supposing that the particle is certainly at first somewhere in the packet; where is it later? Evidently still in the packet, so it must have travelled with the speed of the packet. But here comes an important point; the particle's speed can not be fixed accurately in this way, because the packet is spreading. Thus if we imagine that the particle was moving at the head of the packet it would be going faster than if it were at the tail; and it would be going still faster if it started at the tail and ended at the head. So our idea that the particle may be anywhere in the packet carries with it the implication that the speed is to some extent indefinite. In this way we see that our idea of duality will only work on the condition that there is some indefiniteness in the position and speed of the particle.

The indeterminacy can be expressed in a more definite form. Thus in a very long wave packet the position of the electron is very uncertain, but as such a packet does not spread much the speed is rather precise; on the other hand, a short wave packet will clearly define a rather accurate position for the electron, but such a packet spreads very quickly, and this implies great uncertainty in the speed. It is possible to give rough numerical limits to the two uncertainties; suppose that we measure position in centimeters and speed in centimeters per second, then it happens by a sort of numerical accident that for electrons the product of the two uncertainties is about 1. For example, if I know for sure that an electron is somewhere within a distance of a hundredth of a centimeter from some place, then the uncertainty principle asserts that its speed must be uncertain to about a hundred centimeters a second, so that it would only stay for sure in the region where I had located it for a ten-thousandth of a second. At first sight this seemed a fantastic result, and it is little wonder that it was only recently discovered that it is entirely sensible and natural.

In order to justify our dualistic hypothesis then we have got to show that there is something wrong with the simple idea that we could measure anything we please as accurately as we please. We shall discuss the case of the electron because on account of its being the lightest thing in the world, it provides the most crucial case; the uncertainties for other bodies are always less, and are small beyond conceivable observation for bodies of ordinary size. We have got to show that it is not possible to measure simultaneously the position and speed of an electron with precisions higher than those allowed by the uncertainty principle; and we must recognize that if any one can contrive a method by which he can better these precisions, then the whole structure of modern physical theory collapses, and we know nothing about the foundations of nature. It was the great achievement of Heisenberg to show that all is well with our theories.

We have to devise an experiment which is simultaneously to fix the position and velocity of an electron with the highest possible precision. The easiest way to fix a position with accuracy is to take a microscope, and we can simplify the question of speed by supposing the electron motionless. Our experiment then consists in looking through a microscope at a stationary electron; it is not actually a practical experiment, though very nearly so, but that does not matter because our object is to prove that it would not work with unlimited accuracy even if it were practical. We now have to consider the question of the accuracy of our instrument. The question of speed is easy, because, if the electron stays near the same place for a considerable time, it obviously has very small speed, and so we can check the speed to be zero as closely as we like by taking a long time over the observations. As to the accuracy with which we can observe the position, I must cite certain well-known characteristics of the microscope. If we take the highest possible power of a microscope, and look at a series of objects each smaller than the last, we find that though the larger ones can be seen in sharp detail, when we come to the smaller ones that is not so—their sharper corners seem to be rounded and hazy; and finally we get down to objects which can only be seen as round discs, though they may really be as angular as the larger ones. This failure is easily explained from the wave theory of light; it is never possible to see detail of a scale smaller than the wave-length of the light illuminating the object. The wave-length of visible light is about one-twenty-thousandth of a centimeter, and so if we are to use ordinary light we certainly can not decide the position of our electron more precisely than this. We can do better, however, by imitating the process used in microphotography, which considerably extends the range of visibility by the use of ultra-violet light. But whereas in the practical technique of the microscope it is hardly possible to double the resolution by these means, we are not so limited in our idealized experiment; we may take a wave-length many thousand times smaller. For our purpose the x-rays would be good, but still better are the γ-rays of radium, which have a wave-length about a hundred-thousandth of that of visible light say, roughly, a ten-thousand millionth of a centimeter. With a microscope using this illumination we really can do something. But when we set the apparatus up we find a curious thing; the electron may be there at the beginning of the experiment, and may be at rest, but something always happens so that the electron gets knocked away, and our experiment is ruined every time. We must see how this comes about.

About nine years ago, A. H. Compton was led to consider the question of the way in which an electron would react to light. This is, of course, an old problem, but the virtue of Compton's method was that he regarded it is a collision of two bodies, a light particle and an electron-particle. This was long before the wave aspect of the electron was dreamt of, and though the particle aspect of light was known, no one had as yet taken it so seriously. He found that an electron can only scatter light by itself being set in motion, and worked out the various relations for the scattering of the light and the recoil of the electron. He then verified his predictions very fully, so that in speaking of the Compton effect we are not referring to an abstract doctrine but to hard fact. Compton showed that the recoil of the electron is insignificant for visible light, is easily perceptible for the shorter wave-length of x-rays, and attains very large values if the light has the extremely short wave-length of the γ-rays.

We can now see where our experiment is going to go wrong. We may compare our problem to that of the biologist who wants to study the life-history of some cave-dwelling animal which dies if the faintest light falls on it; the animal is killed by the mere attempt to see how it lives. In our case there is no difficulty about imagining that an electron-particle is absolutely at rest in some absolutely exact place, but it is useless to imagine it because it is unverifiable. We can not verify that it is there without light to see it by, and if we want to know the position with high accuracy we must use γ-ray light. But this light can only reveal the electron provided it is scattered by the electron; and when it is so scattered there is bound to be a recoil, so that even if the electron was at rest before, it will not be at rest after the scattering. So we can not fix the position exactly without thereby spoiling the velocity. If, on the other hand, we are content with a rather rough knowledge of the position we might use ordinary light in our microscope, and thus only get a very small recoil; we have sacrificed knowledge of position and have gained a greater precision in our knowledge of the speed. When it is worked out in detail, the result of our experiment is in exact conformity with the uncertainty principle; that is to say, we can fix either position or speed as accurately as we please, but either only at the expense of the other.

The microscope is evidently not going to help us in breaking the uncertainty principle, because of the tiresome way in which the light makes the electron recoil, and we therefore try again, this time without the use of light. Suppose, for example, that we have a source of electrons to the left of two screens. The screens have very fine holes cut in them, which are closed with shutters most of the time. We first open the left-hand shutter for an instant, and then the right-hand one for an instant. Any electron which is found to the right of both screens must have come along the line of the holes, and must have taken a definite time in doing so. Surely we now know position and velocity as accurately as we like, by making the holes very small and only opening them for very short times. Quite true; we can say where the electron was, but not where it is, since on its emergence from the second hole the electron will be scattered into some arbitrary direction, like the wave going through the gap in the sea-wall. We have, in fact, only succeeded in practicing the noble art of foretelling the past. Once again we see that our idea of the particle as occupying a sequence of exact positions is a useless one, because the experiment devised to tell us what the position is will always disturb the particle giving it a velocity that it would not have had if we had not made the experiment, and so making the determination useless.

The general outcome of this and other experiments is always the same, and may be summarized thus. If we were conservative and did not believe in all the new ideas, we should regard the electron as a little piece of grit, and therefore located at some precise place and possessing some definite speed of motion all the time. But in adopting this belief we lay ourselves open to the challenge of being asked to prove what the position and velocity are; and when we come to examine the details of the appropriate experiments, we find that the values will always elude us, and remain undecided to just the extent suggested by the uncertainty principle. There is, therefore, no warrant for our conservative assumption, and, on the other hand, there is no contradiction in the dualistic ideas of wave and particle. Before going on I ought to say that I have simplified the question by only discussing the case of the electron. The uncertainty principle applies to everything else as well, and the only reason why I have not discussed the other cases is that the electron provides the extreme case, so that if it can be met there, all the others are easy.

The uncertainty principle has very radically altered our views about one of the fundamental principles of knowledge, the principle of causality. We used to think that there was an absolute causality in the world; that a full knowledge of the present would inevitably lead to certainty about the future. It is true that the force of the principle was much reduced by the fact that we usually had to confess to so much ignorance about the present that we could excuse ourselves from any great self-confidence in prophecy; but we used to feel it as a slight reproach that we suffered from this ignorance, and to imagine that our descendants would become perfect prophets because they would be omniscient. But now we see that the present is definitely unknowable, so that there is no possibility of foretelling the future with certainty. Every time we determine something in the present we spoil something else; and we are always at least one step behind what we need for the purpose of confident prophecy. Instead of certainties we have to deal with probabilities, and the theory of chance is raised to a more dignified position than it used to occupy; it is no longer a confession of ignorance of things we feel we ought to know, but of things essentially unknowable.

Closely allied with the question of causality is the question of free will and determinism, which has puzzled the philosophers of all ages. It is really not a matter for the scientist, but it is impossible to conclude without a reference to it. What I am now saying has none of the authority of scientific knowledge behind it, and it is improbable that any one will agree with it. I can lay no claim to philosophic knowledge, but my views certainly resemble those held by some philosophers in this, that they change every few months. In spite of the great effect that the new theory has on the idea of causality I believe it leaves the question of free will where it was.

There appear to me to be two radically different kinds of free will, which may be called *my* free will and *your* free will. When I think about my free will, I conceive myself standing right outside the operations of nature, making arbitrary decisions without reference to causes of any kind, such as the decision whether I shall raise or lower my hand. When I observe your free will, it seems to me to be a very inferior thing, a certain capriciousness in your actions, for example a perfect uncertainty as to whether you will raise or lower your hand; in fact, though you claim that you are really displaying my kind of free will, yet as far as my observation goes your actions have the same sort of uncertainty as that displayed by an electron. It used to be felt by some that the old inexorable laws of nature allowed no latitude for this capriciousness, and that now that we have found that those laws were wrong, we have escaped from the rigid determinism that they implied. I do not think this is the real point. Though the behavior of a single electron is very uncertain, that of a thousand will be fairly regular, and when we come to the large number of electrons in the human body we expect a very complete regularity. The human body will be governed by the new laws of nature almost as rigorously as by the old, but when we consider the enormous complication of a human being, and the complete impossibility of knowing even roughly what all the parts of the human machine are doing, this rigor need not trouble us, for even before the advent of the uncertainty principle our ignorance was surely ample enough, and was evidently always going to be ample enough, to prevent any confident forecast of our actions. So I conclude that there was no great difficulty about *your* free will even before the discovery of the new principles, and that the philosophic difficulty is just what it was before, the intolerable contradiction between *my* free will and *yours*.

It is possible that these difficulties will always remain to puzzle us, but it really does not seem to matter very much whether they do, whatever their appeal to the introspectionist may be. It is the scientific meaning of the new theory that is of permanent value. The earlier direct experiments with atoms revealed certain contradictions. The new quantum theory removed these contradictions, but seemed at first to be composed of the most fantastic abstractions. It was the uncertainty principle that revealed the common sense of these abstractions.

SOME ATTRACTIONS OF THE FIELD STUDY OF ANTS

By Dr. WILLIAM MORTON WHEELER
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AFTER more than thirty years devoted to the study of ants I find myself wondering why so very few of our nature lovers have engaged in this pursuit. I find that observing and collecting ants in many lands, quite apart from the benefit to my health, have yielded a keen delight which has remained with me and seems to have colored my recollections, so that I have acquired the habit, when regrets and unpleasant memories assail me, of effacing them with the memories of excursions in mountains, forests and deserts peopled by colonies of thrillingly interesting ants. Certainly the pursuit of any branch of natural history may be recommended as an avocation to our youth, to convalescents, to our tired business men or in fact to any one who craves a hobby, a surcease from the nerve-racking routine of our city life or a valid excuse for remaining as many hours as possible in the open air of the woods and fields.* But no branch of natural history, in my opinion, is so well adapted to furthering these ends as myrmecology. I shall therefore discuss some of the advantages of ants as material for observation and study, and add a brief account of the simple equipment needed by the field and laboratory observer in the hope that some of my readers may be persuaded to join the ranks of the myrmecologists. In conclusion I shall call attention to a few of the many problems to the solution of which the patient and enthusiastic student of these insects may hope to contribute.

The ants, unlike many other insect families, are represented by comparatively few species in any given locality, but, being social organisms, this deficiency is compensated by the great numbers of individuals even in very circumscribed areas. The observer, therefore, always has an abundance of material at his disposal without being confused by such a maze of species, represented by comparatively few individuals, as he would encounter in many families of flies, beetles, moths, etc. The number of species, subspecies and varieties of ants scarcely exceeds 60 in any of our New England states, and the entire ant fauna even in any one of our Southern or Southwestern states does not exceed 100 to 150. The fact that ants can be so easily collected, since their most abundant caste, the workers, are wingless and the males and females take to their wings only during the marriage flight, may also be cited as greatly facilitating their observation and study. Nevertheless, fear seems to have prevented many people from making an intimate acquaintance with these insects, though few of our North American forms can sting or bite painfully and the great majority of them are only feebly aggressive or even decidedly timid. Probably most people are so annoyed by the sensation of ants crawling over the skin that they fear to disturb colonies. This aversion, however, is soon overcome. There are, of course, certain stinging species like the agricultural ants (Pogonomyrmex) of our Western states, the driver ants (Dorylus) of Africa, the legionary ants (Eciton) of Tropical America, and the bull-dog ants (Myrmecia) of Australia, which make much greater demands on the fortitude of the observer. Excepting in such species, however, which equal or even surpass the honey-bee, bumblebees and wasps in aggressive and stinging behavior, the economy of ants, as compared with that of very many insects, is singularly open to observation. The structure of their nests, the whole personnel of their colonies, the peculiarities of the various castes of adult ants, all the different stages of the brood from egg to pupa, can be examined without any difficulty. The marriage flights of the males and females, the expeditions and wars and the founding and development of the nests and colonies also furnish inexhaustible material for study in the field.

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* As the Australian myrmecologist, Mr. John Clark, remarks: "The study of ants is most interesting, and entails very little exertion. It should appeal to those whose health does not allow of vigorous work in the bush. It keeps the observer in the open, with his mind fully occupied, so that life's worries are soon forgotten, while a store of valuable information is gained. Ants are numerous everywhere. They are easily kept in artificial nests, and make interesting pets. The food required by them is always at hand, and the nests are readily made; so that no one should experience much difficulty in keeping ants for observation at home."

Ants are so extremely sensitive to the degrees of temperature and humidity of their environment and to the character of its vegetation that many species or subspecies are confined to very narrow ecological habitats. This specificity of adaptation also furnishes interesting matter for study, especially in connection with the fact that nearly all species of ants are highly variable and exhibit many subspecies or geographical races and even more numerous varieties characterized by subtle peculiarities of color, hairiness and sculpture. Hence the great importance of the ants as material for the investigation of geographical distribution, variation and polymorphism. An even more fascinating field for observation is afforded by the intricate relations between ants and other ants and between ants and other organisms, both animal and plant. To the former relations belong the phenomena of inquilinism, social parasitism and slavery, to the latter the relations of ants to certain peculiar plants (myrmecophytes) and myrmecophily, or the extraordinary relations of the ants to their insect guests, parasites and "cattle" (plant-lice, scale-insects, certain butterfly caterpillars, etc.). Field observation thus broadens out into a study of great scope and complexity and comprises many cases of the most marvelous behavior, both on the part of the ants and of their charges, known to occur among insects.

Finally a word may be added concerning the esthetic aspect of myrmecology. Ants are not usually regarded as beautiful insects, and this is probably responsible for their neglect by many entomologists. There are, however, in the tropics some very beautifully colored forms, notably in Cuba and Australia, which possess a number of gorgeously metallic green or purple species, but those of temperate regions are apt to be merely dull yellow, reddish, brown or black. Yet even these species when viewed under a low magnification are by no means unattractive. Indeed, the form of the body, especially of the workers and males, is decidedly graceful, and the texture of the integument, with its endless variety of fine sculpturing, polish and luster and its delicate pilosity is in many species exquisitely beautiful. Unfortunately, we possess no really artistic illustrations of ants, like the famous pictures of birds, beetles, butterflies, etc., because as yet no gifted artist has interested himself in these insects.

Since field observations on the behavior of ants can be of little value without a recognition of their various species, subspecies and varieties, it is necessary to collect and preserve specimens for comparative study and as essential records of observation. This taxonomic or classificatory aspect is less irksome in myrmecology than in the study of many other groups of insects for the reason, already mentioned, that the various forms occurring over a considerable area are not very numerous. The field worker will readily become acquainted with the majority of the forms in his state during a single season, but it may require several years for him to find all the rarer forms that nest in concealed situations. Often their colonies can be located only by carefully following accidentally encountered worker individuals till they return to the nest and thus betray its site. Even this method is impossible, however, in the case of certain minute subterranean forms, which rarely or never appear on the surface of the soil. These can be secured, as a rule only by using the Silvestri funnel described below.

The apparatus for field work in myrmecology is very simple and easily obtained. It comprises the following articles, all of which can be carried in the pockets of an outing jacket.

(1) Some cloth bags, each capable of containing about two or three quarts of earth.

(2) A large white handkerchief or a piece of white oil-cloth about a square yard in area.

(3) A number of vials of ethyl alcohol, or if this can not be readily obtained, of methylated or denatured alcohol.

(4) A pair of tweezers with fine, or preferably, with smooth, narrow, flattened points.

(5) A short, strong chisel, with a blade about an inch in diameter, a small trowel or a strong-bladed plasterer's knife.

(6) A good pocket-lens. An excellent one, with magnifications of 10 and 20 diameters is supplied by the Zeiss or Leitz optical companies.

(7) A note-book.

The uses of these articles, with the exception of (1) and (2), will be obvious. An ant nest is dug up with the chisel or trowel and the earth, detritus or dead wood quickly thrown on the piece of cloth which has been spread on the ground. The material of the nest can then be carefully broken up and the ants or any other insects associated with them collected with the tweezers before they can escape. The bags are used for holding entire small or selected portions of large nests which are to be carried home or to the laboratory for more careful inspection and collection than is usually possible in the field or for instalment in artificial nests.

To the articles listed above two pieces of apparatus, the "exhaustor" and Silvestri's modification of "Berlese's funnel," have been added very recently. They are so useful to the field myrmecologist that I here figure and describe them in greater detail. The exhaustor (Fig. 1) consists of a strong, wide-mouthed vial (A) furnished with a cork or rubber stopper (B) perforated for the accommodation of two tightly-fitting

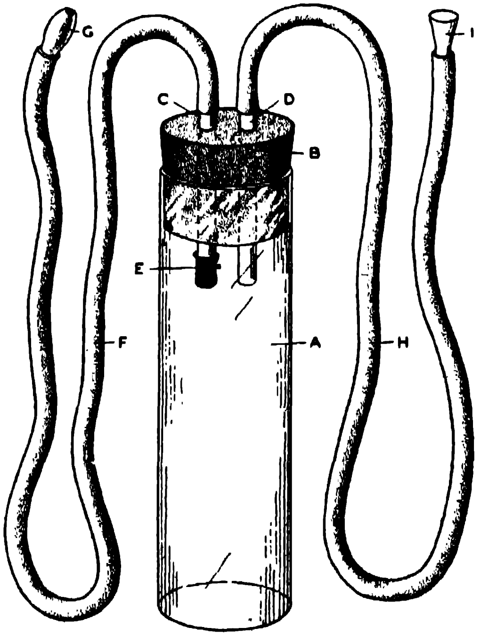

FIG. 1. THE EXHAUSTOR

glass or metal tubes (C, D). The upper end of each of these tubes is fitted into a flexible rubber tube 12 to 18 inches long, one of which (F) ends in a perforated mouthpiece (G), the other (H) in a small glass funnel (I). Neither of these attachments, however, is really necessary. The lower end of the tube C is covered with a cap of gauze (E). If this tube is made of metal instead of glass a small piece of fine wire netting soldered to the walls of its opening may be substituted for the gauze. In using the exhaustor for collecting ants and other small insects running over the ground, tree-trunks or foliage the vial is held in the left hand, the mouthpiece is placed between the lips and the opening of the funnel or the end of tube H is placed over the insect, which can then be sucked into the vial. Large numbers of extremely delicate Arthropods, such as small beetles, Pauropods, Thysanurans, springtails, mites, gnats, ants, etc., which are apt to be more or less injured if picked up with the tweezers or even with a brush dipped in alcohol, may thus be captured in perfect condition. If the collector carries a supply of vials of the same size as that of the exhaustor he can, after making a collection, remove it from the cork and substitute a fresh vial as often as desired. The captured insects can be either kept alive or killed and preserved by pouring a small amount of alcohol into the vial. The exhaustor seems to have been invented by the economic entomologists to avoid handling delicate insects with the tweezers or fingers. It should be of considerable use in physiological experimentation whenever it is necessary to move insects about without injuring their delicate wings or articulations or infecting them with foreign odors. The exhaustor is also very useful in transferring living ants from one artificial nest to another. A little practice with the instrument in the field will enable the collector to capture a great number of uninjured specimens in a very short time compared with the old and laborious method of picking them up one by one with the tweezers.

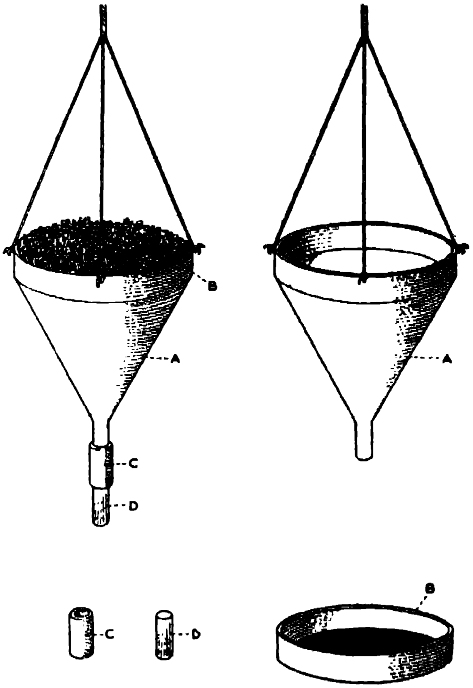

FIG. 2. SILVESTRI'S FUNNEL

The Berlese funnel is an apparatus which collects minute Arthropods automatically from samples of humus or soil. In its original form it was rather cumbersome and not easily manufactured, but Silvestri has simplified its construction without impairing its efficiency. I translate his account and reproduce his figure (Fig. 2).[1] "The apparatus suggested by me was described by Mr. E. Jacobson[2] after he had used it for several years according to my directions. It is very simple, consisting of a funnel (A), which can be suspended by three cords wherever desired; of a sieve (B), with meshes one to two millimeters in diameter, and a glass vial (D) containing alcohol and attachable to the end of the funnel by means of a piece of rubber tubing (C). This apparatus, thus simplified, is very convenient, especially for traveling naturalists, because they can have two or more funnels made, of slightly different diameters, so that they can be fitted one inside the other and thus occupy but little space. In my travels I have always had with me since 1908 three of these funnels, which have never caused me any inconvenience. . . . This apparatus may be made of sheet zinc or, more economically though less durably, of tin. It requires no attention after the selected material [humus, detritus, soil, etc.] has been placed in the sieve, [this set in the top of the funnel], and the vial of alcohol attached to the end of the funnel. The length of time the material should be left in the sieve is very variable, depending on the quantity and humidity of the material and the temperature and humidity of the surrounding air." With the gradual drying out of the contents of the sieve, the minute insects fall one by one into the funnel and thence into the vial of alcohol at its lower end. "This simple apparatus," as Silvestri states, "should be used by all entomologists interested in the microgenton and especially by those who have an opportunity to live for some time in tropical regions where it is still possible to discover many interesting Arthropods." He coined the term "microgenton" to embrace all the minute, poorly pigmented and usually blind Arthropods that inhabit vegetable mold, soil, dead leaves, decayed wood, etc. Quite a number of our smallest ants belong to this remarkable ecological association and are very difficult to collect without the aid of the funnel above described.

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[1] F. Silvestri. Aparato para recolección de pequeños Artropodos. Conf. y Res. Real Soc. Española de Hist. Nat. Madrid, p. 10–13, 1 fig., 1930.

[2] E. Jacobson. Hilfsmittel beim Fang und Präparieren von Insekten, besonders in den Tropen. Deutsch. Ent. Nation. Bibliothek 1, pp. 94–95, fig. 8, 1910.

Perhaps in this connection another and very different piece of labor-saving collecting apparatus should be mentioned, namely, the automobile. Its value to the field myrmecologist especially, in enabling him to visit remote and unfrequented territory without fatigue and loss of time, can not be exaggerated. It will probably be found that both private and museum collections have greatly increased the number and variety of their accessions, especially of insects and other invertebrates, since the automobile came into general use.

The myrmecologist will be led naturally to supplement his field observations with observations in the laboratory. Though this may be as unpretentious as any small well-lighted room in a house, he will wish to equip it with the apparatus both of the entomologist—insect boxes, insect-pins, labels, etc., and those of the histologist—compound microscope, binocular dissecting microscope and the usual glassware and reagents. He will also need a number of artificial nests for living colonies of ants. I have described some of the various patterns of these in an appendix to my ant book,[3] and a few others in a note published in 1910.[4] During recent years I have found that colonies of small ants can be kept for some time in ordinary Petri dishes, provided the optimum supply of humidity and food is maintained. The colonies can be readily transferred when required from fouled to clean dishes, by means of the exhaustor.

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[3] W. M. Wheeler. "Ants, Their Structure, Development and Behavior," Columbia Univ. Press, N. Y. 1910; reimpr., 1926.

[4] W. M. Wheeler. "Small Artificial Ant-nests of Novel Patterns," *Psyche*, April, 1910, pp. 73–75, 1 fig. There is an excellent chapter on artificial nests and on collecting and preserving ants in H. Donisthorpe's "British Ants," 2nd ed., 1917. The following recent literature on ant-study and artificial nests may also be consulted with profit: H. Kutter, "Züchtung von Ameisen," in E. Abderhalden's "Handbuch der biologischen Arbeitsmethoden," 1926; A. Stärcke, "Ein neues Formicarium," *Zool. Anzeig.*, 92, 1930, pp. 152–155; H. Eidmann, *Zeitschr. f. vergleich. Physiol.*, 3, 1926, pp. 776–821, and 7, 1928, pp. 39–55; E. Meyer, *Biol. Zentralbl.*, 43, 1923, pp. 353–404 and 47, 1927, pp. 264–307.

The beginner in myrmecology may become disconcerted or even depressed when he discovers what an enormous mass of literature on the ants has been produced during the past two centuries. The veteran investigator may, perhaps, encourage him with the statement that we are only just entering on the more experimental and statistical and therefore more serious, interesting and enlightening study of these extraordinary insects. It is generally agreed that ants communicate with one another, but the precise character and scope of this behavior in the various species have never been satisfactorily ascertained. The same is true of the homing behavior, though it has been the subject of much valuable experimental investigation. We are still very much in the dark in regard to the feeding of the larvae by the workers and therefore of the precise method of determining the development of the various castes (polymorphism), which are such a striking feature of the ant community. Our knowledge of the parasitic and slave-making ants and of the interrelations of ants and myrmecophiles remains very sketchy. We possess no satisfactory information concerning the factors that initiate and control the movement of ant colonies to new nesting sites. The population of an adult ant-colony seems to be a true specific character, but we have almost no statistical data on the number of ants in fully developed colonies in various species, on the rate of the development of colonies or on their life-span. Moreover, certain investigations which have been carefully pursued in Europe have never been extended to our American ant fauna, such as those relating to the interesting transportation and distribution of plant seeds (myrmecochory). This list of matters awaiting further elucidation might be indefinitely increased. For the solution of those mentioned the ant-fauna of the United States, which is so much richer than that of Europe, should afford adequate material, without resort to the splendid but less easily accessible neotropical fauna of the West Indies, Mexico and Central America. We only need more myrmecologists.

CANNIBALISM AMONG THE SHARKS AND RAYS

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THE elasmobranchs are the lowest of the great group of backboned animals. They have no ribs and their skeletons, instead of being bony, are made up of cartilage. The higher fishes have their gills in one gill-chamber covered by a bony operculum or cover with one opening for the discharge of water. The elasmobranchs have no gill cover, but each gill has a separate opening. These openings are separated by straps of skin and flesh, hence the name elasmobranch (strap-gilled).

It has long been known in a general way that these animals feed on each other, but no attempt has ever been made to set the facts out in order. How I have been led to take up this (to me) interesting task will be indicated below.

SHARKS FEEDING ON STING-RAYS

Everywhere that I have fished for sharks, my fishermen helpers have advised the use of the flesh of sting-rays as the best available bait. Indeed at Key West and at the Marine Biological Laboratory of the Carnegie Institution of Washington, at the Dry Tortugas, Florida, where I fished rather extensively for sharks for four seasons (1912 to 1915) we used to hunt for sting-rays to use their fins as bait.

With this sting-ray bait we always had better success than with anything else. A professional shark fisherman, Captain W. E. Young, of Brooklyn, N. Y., tells me that he always uses ray bait when possible. He has for many years fished for sharks all over the world and has more first-hand knowledge of methods of catching these fish than any man known to me. However, I had long known that at least one kind of shark was very partial to sting-ray flesh. This I reported in *Science* (Vol. 25, pp. 1005–1006, 1907).

THE HAMMER-HEAD SHARK A STING-RAY EATER

Late in July, 1906, numbers of large sharks were seen in the inner harbor of Beaufort, N. C. On July 20, a big hammer-head (*Sphyrna zygaena*) was seen chasing sting-rays over the sand flats. Presently it came near an anchored sharpie and was harpooned, but the "iron" pulled out. However, when it chased the sting-ray across the bow of the boat again, it was again harpooned, and this time the harpoon held and the shark was secured. Eighteen hours later I purchased the fish, towed it to the laboratory of the U. S. Bureau of Fisheries, hoisted it up on a davit on the wharf, and there skinned and dissected it. This huge specimen was 12 feet, 6 inches long; 4 feet, 2 inches in girth; 3 feet wide between the eyes; and had the dorsal lobe of its tail measuring 3 feet, 6 inches in length. Fig. 1 shows it suspended from the davit ready for skinning and dissection.

This specimen was a female and was dissected in the hope that embryos might be found in the oviducts. In this matter I suffered a keen disappointment. but on opening the stomach I was surprised to find the almost perfect skeleton of a sting-ray, together with cartilaginous fragments of other such skeletons. Furthermore, when I began to work the skin away from the lower jaw and throat region of the shark the most surprising thing of all came to light—these parts

FIG. 1. A LARGE HAMMER-HEADED SHARK

THIS 12-FOOT, 6-INCH SPECIMEN OF *Sphyrna zygaena* IS HERE SHOWN SWUNG UP BY A DAVIT AT THE WHARF OF THE LABORATORY OF THE U. S. BUREAU OF FISHERIES AT BEAUFORT, N. C. NOTE THE MALLET-LIKE PROLONGATIONS THAT GIVE THIS SHARK ITS NAME. THE EYES ARE AT THE OUTER EXTREMITY OF THESE.

were found to be full of sting-ray stings, one even being found in the back. Later, when the jaws were being cut out and cleaned up, they were found to be a perfect mine of stings.

On the day following the removal of the skin, about forty hours after the capture of the shark, I began the work of cutting out and cleaning the jaws. With the July temperature at Beaufort well up in the eighties, the shark was in a pretty "high" condition, so the jaws were cut out and the shark thrown overboard. The jaws were then carefully dissected. In cleaning them more than 50 stings were found embedded in the muscle masses adherent to the jaws, and stuck in the membrane covering over the cartilages of the jaws. Sometimes as many as three or four tips of stings were found in a cube of flesh an inch square and two inches long. Furthermore, the lower jaw cartilages from one corner of the mouth to the other were scarred and ridged—evidently the results of former combats in which the rays had used their spines effectively.

A total of 54 fragments of sting-ray stings were found. These vary from large pieces three and four inches long (at least half the spine) to small points only one half inch in length. In addition, four pectoral spines of the gaff-topsail catfish were found. These 58 spines were taken mainly from the jaws and the adherent flesh. Some, however, came from the neck region. The flesh around some of these stings was still full of congested blood, showing that the stings were but newly implanted. Others (especially those piercing the membranes covering the jaw cartilages) were embedded in cysts, showing that they had been carried for a long time. When this very extensive "mine" had been "worked," I greatly regretted that, despite its offensive condition, the body had not been kept and thoroughly dissected for spines. Had this been done undoubtedly many more stings would have been found in the neck and chest region.

Fig. 2 shows the 54 fragments of sting-ray stings and at the top the four pectoral spines of the ocean catfish (*Felichthys felis*) which were collected. All the stings were broken, save the one with the forked base, which was torn out intact. It is from the spotted sting or eagle ray, *Aetobatus narinari*, while the others are probably from the black sting-ray, or "stingaree," *Dasyatis say*,

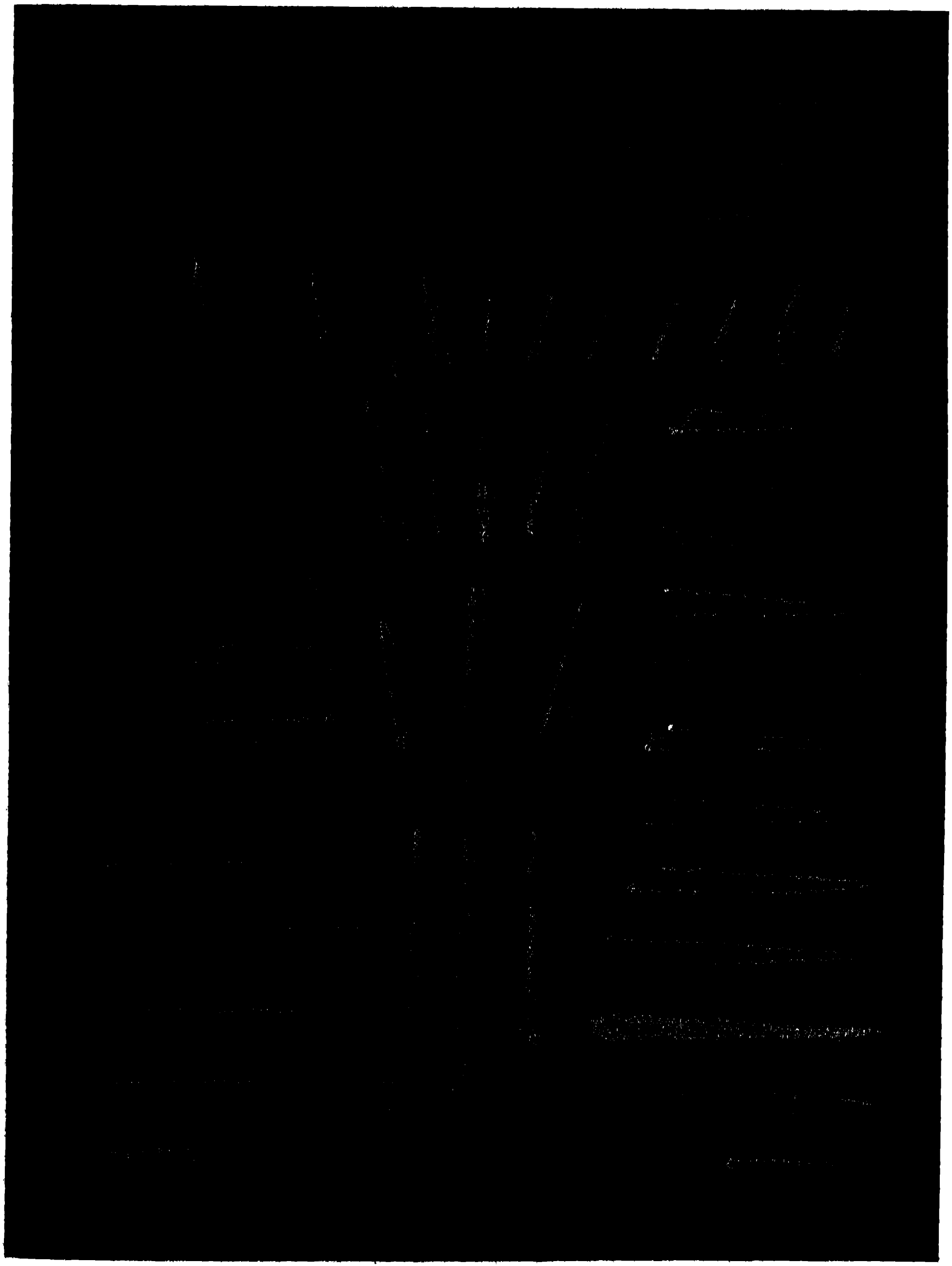


FIG. 2. A PANEL OF 58 STINGS OR SPINES DISSECTED FROM THE HAMMER-HEADED SHARK

OF THESE 54 ARE FROM THE STINGAREE AND THE SPOTTED EAGLE-RAY, AND AT THE TOP ARE 4 PECTORAL SPINES FROM THE OCEAN CATFISH. THESE WERE TAKEN FROM THE JAWS AND NEIGHBORING PARTS OF THE SHARK SHOWN IN FIG. 1.

FIG. 3. THE LOWER JAW OF THE BLACK-TIPPED SHARK

THIS JAW OF *Carcharhinus limbatus* (SEEN FROM ABOVE) SHOWS A STING-RAY SPINE BETWEEN THE TWELFTH AND THIRTEENTH ROWS OF TEETH ON THE LEFT AND ANOTHER BETWEEN THE FIFTH AND SIXTH ROWS ON THE RIGHT. SPECIMEN IN THE COLLECTIONS OF THE AMERICAN MUSEUM.

the commonest sting-ray at Beaufort. The tail of the latter is used as a whip, and I have seen a large ray caught in a seine lash out savagely with its tail and drive its sting so deeply into the side of a boat that the ray could not free itself save by breaking off the sting. The large spine at the bottom of the figure was torn out by the root. However, it has its tip broken off. The same things are true of the short basal part of a spine just below the center of the figure.

These serrated stings will easily penetrate a leather shoe or a rubber boot and will cause very formidable and painful wounds very hard to heal. Fishermen and writers on fishes in all ages and climes have claimed that these wounds are poisonous. These stories even go back to classical antiquity, from which times fearful accounts of severe lacerated wounds have come down. Of them Francis Day writes in his "Fishes of Great Britain and Ireland" (p. 351, London, 1880) that:

> Pliny, Aelian, and Appian asserted that the venom with which it was endowed was capable of causing injury to even vegetable and mineral substances, trees losing their verdure, and rocks being even affected. Circe armed her son with a spear which she pointed with a Trygon's [a huge sting-ray's] spine as the most formidable weapon she could place in his hands, and with which he subsequently unintentionally slew his father, Ulysses. Anyhow, these wounds are dangerous, for at Cochin I have had to amputate the arm of a native which was mortified owing to a wound from one of these fishes having divided the muscles and other structures almost to the bone.

These accounts, like most that have come to me from fishermen, are greatly exaggerated, but the essential facts are incontestable. I long thought that the effects following a stinging by a stingaree were due to infections from bacteria carried in with the slime covering the spines. But investigation showed that the dreadful pain and swelling following immediately on the infliction of the wound were too rapid and severe to be explained by bacterial infection. So then I fell back on the explanation that the almost immediate effects were due to the slime acting as a chemical poison when injected into the circulation. Now, however, thanks to the researches of an English surgeon, Dr. H. M. Evans, we know that there is at the base of the spine of the sting-rays a small poison gland and that its secretion flows down the groove of the spine and by this is carried into the flesh and blood of the victim. Fortunately, however, this secretion is only moderately poisonous, compared with that secreted by the poisonous snakes and even by certain bony fishes—*e.g.*, by *Synancia* and its allies. Furthermore, even as some snakes are impervious to the poison of other snakes, so the hammer-head seems immune to the poison of its cousin, the sting-ray. Sharks seem also largely devoid of feeling. Certainly the specimen under consideration must have been so since it attacked and was "stung" by at least 54 stingarees and 4 catfish—these adventures evidently covering quite a space of time.

So far as I can find in the literature examined there are on record but two other published observations of this habit of the hammer-head in feeding on rays. The late Russell J. Coles, in his observations on "The Large Sharks of Cape Lookout, North Carolina" (*Copeia,* no. 69, p. 42, 1919), speaks of examining large and presumably old hammer-heads at Cape Lookout which "subsisted exclusively [?] on sting-rays, which, as far as observed, were *Dasyatis.*"

While reading the proof of the above, I received a most unexpected and interesting confirmation of this ray-eating habit of the hammer-head. Mr. Henry W. Fowler in describing certain fishes from Florida (*Proceedings Academy Natural Sciences Philadelphia,* vol. 78, p. 249, 1926) writes thus of a female hammer-head 13.2 feet long taken at Captiva Pass by Mr. R. D. Benson, Jr., dissected by him and the following data supplied:

> In the stomach . . . were 3 rays (evidently *Dasyatis sabina*) with a disc length of 18 to 24 inches, and in the mouth 1 ray of 20 inches. There were also remnants of 17 caudal spines in the stomach, the largest complete 3 inches and the largest estimated at 4 inches. The jaws were also punctured with other spines and at least 24 spines in the gum.

Had the jaws, neck and chest region been carefully dissected by Mr. Benson it is probable that he would have gotten an even greater number of sting-ray stings than I did. It is a great pity that he did not preserve these jaws with the stings in place. Mr. Fowler has sent me 12 of these stings, which I find counterparts of mine.

Earlier than he, however, Francis Day, in his "Fishes of Great Britain and Ireland" (Vol. II, p. 294, 1884), had recorded the fact that in the stomach of a 13-foot, 7-inch hammer-head taken in 1865 near Ilfracombe, on Bristol Channel, two thornback rays had been found.

From the very definite data given above it can not be doubted that large hammer-headed sharks feed largely on sting-rays. However, it has long been held that in general the hammer-head and the closely related bonnet-head (*Sphyrna tiburo*) seem to be bottom feeders and various writers have reported their stomach contents to consist sparingly of squids and largely of crabs, shrimps and other crustaceans; and of such fish as go in schools, menhaden and mackerel, etc. Coles reports mackerel and thinks it the chief food of the hammer-head.

THE BLACK-TIPPED SHARK A FEEDER ON STING-RAYS

In the collections of the American Museum are a considerable number of sharks' jaws labeled as sent in from the Gulf of Aden, an arm of the western Indian Ocean connecting it with the Red Sea. These were presented by the late

FIG. 4. A SECTION OF THE JAW OF THE BLACK-TIPPED SHARK

THIS PART OF THE LOWER LEFT JAW SHOWN IN FIG. 3 IS TO DEMONSTRATE THE STINGAREE SPINE EMBEDDED IN THE CARTILAGE OF THE JAW. IT HAS DIVIDED THE BUD OF THE THIRTEENTH ROW OF TEETH INTO HALVES AS IS SHOWN BY THE HALVED TEETH. SPECIMEN IN COLLECTIONS OF THE AMERICAN MUSEUM.

Dr. Alfred Ehrenreich, then connected with a French company catching sharks to make leather of their hides. Unfortunately no definite localities in this gulf are designated, but Captain W. E. Young, who was then connected with this fishery, informs me that practically all the fishing was done at Djibuti, French Somaliland.

This pair of jaws, which my colleague, Mr. John T. Nichols, has kindly identified as coming from that shark whose scientific name is *Carcharhinus limbatus*, had only been "roughed out." There was considerable muscular tissue attached to both inner and outer surfaces, and the folds of tough tissues, forming the "gums" or thecal folds and covering the reserve teeth, were intact but dry and almost as hard as bone. However, there could be seen between the twelfth and thirteenth rows of teeth in the lower left jaw the broken-off basal part of a sting-ray sting embedded in the gum and cartilage. The point of this protruded on the outside of the jaw cartilage slightly to the left of a vertical line drawn through the middle of this jaw.

This was enough to start me on the rather difficult task of a thorough dissection of these dried jaws. This, when finished, brought to light the following interesting state of affairs. The spine referred to had pierced the tooth bud of the thirteenth lower left row of teeth, resulting in the formation of *two* rows of teeth rather smaller than the normal-sized teeth. This whole lower jaw is shown in Fig. 3, while Fig. 4 is a photograph showing in larger size the broken-off basal part of the enlarged spine. Fig. 5 shows the point of the spine where it has emerged on the outside of the jaw cartilage. From these figures some idea can be gotten of the tremendous power with which the ray lashes out with its tail.

Furthermore, on the lower right jaw just outside of the fifth row of teeth, was found a shorter and smaller spine with its point embedded in the tooth bud tissues at the base of the hollow of the jaw. This spine, in place as found, is shown in Fig. 3. However, as may be seen in Fig. 6 (where it has been removed and cemented to the inner edge of the jaw cartilage), it merely clipped off a small portion of the tooth bud, which has successively given rise to five small fragments set to the right of this fifth row of teeth. The details of these two remarkable teratological rows of teeth will be discussed in another paper.

Further dissection brought to light two other fragments of sting-ray spines embedded in the gums. These have been removed and affixed to the left inner segment of the lower jaw. They are the two larger spines shown at the extreme left in Fig. 6. Three other spines were found stuck in the membrane covering the lower left jaw. Above the two spines referred to was seen on the rim of the jaw cartilage a very small point of a spine. This, being invisible as the jaws were photographed, was removed and cemented to the jaw to the right of the two large spines, as may be seen in Fig.

6. To the left of the two larger points are two small points (one almost too small to show in the photograph) *in situ.*

Dissection of the right angle of the mouth brought to light a similar state of affairs, five spines being concerned. As may be seen in Fig. 6, two tips were found on the inner side of the broad base of the jaw; while on the edge of the jaw cartilage just beyond and to the right of the end of the tooth band are three others. The larger one is broken in three pieces. At its base are two small points of stings found with their apices pointing outward and somewhat toward the symphysis of the jaw. In this connection it should be noted that the small fragment on top of the lower left jaw (referred to in the preceding paragraph) pointed squarely toward the symphysis. It is very difficult to see how these three tips could have been embedded to point as they are found to do.

Just here it may be emphasized that all these spines are in their natural positions, as shown in Fig. 6, save four. The two large stings on the lower left jaw were found pointing in their present direction but set in the gum of the jaw. If put back there they would be difficult to affix and would be largely invisible. The third spine on the edge of the right jaw, about one third to the left of the symphysis, has been taken from its place and affixed where it is shown in order to make visible the divided tooth row—the fifth to the left. The fourth spine is the small point shown to the right of the two larger spines on the left lower jaw. Still another point was found on top of the upper jaw just to the left of the symphysis. It has unfortunately gotten lost.

A total of 13 spines were found in the roughly dissected jaws as they came to my hand. Presumably, and one may almost say undoubtedly, if the muscles attached to the jaws and indeed if the whole throat and chest region could have been dissected, a considerably larger number of stings would have been found. It is plain that this shark had for a long time been feeding on sting-rays. The two larger spines prove this. The one penetrating the tooth bud of the thirteenth row of the lower left jaw, and piercing the very cartilage of the jaw, had protruded on the exterior and in doing so had divided the tooth gum into halves. The other sting had severed the tooth gum into two parts, one large and the other very small. Each interference with a tooth bud had occurred so long ago that the old undamaged teeth have all rotated upward and have wholly disappeared and their places have been taken by the abnormal teeth formed since the injury to the tooth buds. This phenomenon will be referred to later.

THE SHORT-NOSED SHARK A RAY-EATER

The evidence that the short-nosed shark, *Hypoprion brevirostris,* is an eater of sting-rays rests upon the presence of the tip of one sting found adher-

FIG. 5. THE PROTRUDING TIP OF THE STING

THE TIP OF THE STING SHOWN IN FIG. 4 HAS PENETRATED THE WHOLE CARTILAGE OF THE JAW AND HAS EMERGED ON THE OUTSIDE. THIS EFFECT COULD ONLY HAVE BEEN PRODUCED BY A VERY STRONG LASHING OUT OF THE TAIL. SPECIMEN IN COLLECTIONS OF THE AMERICAN MUSEUM.

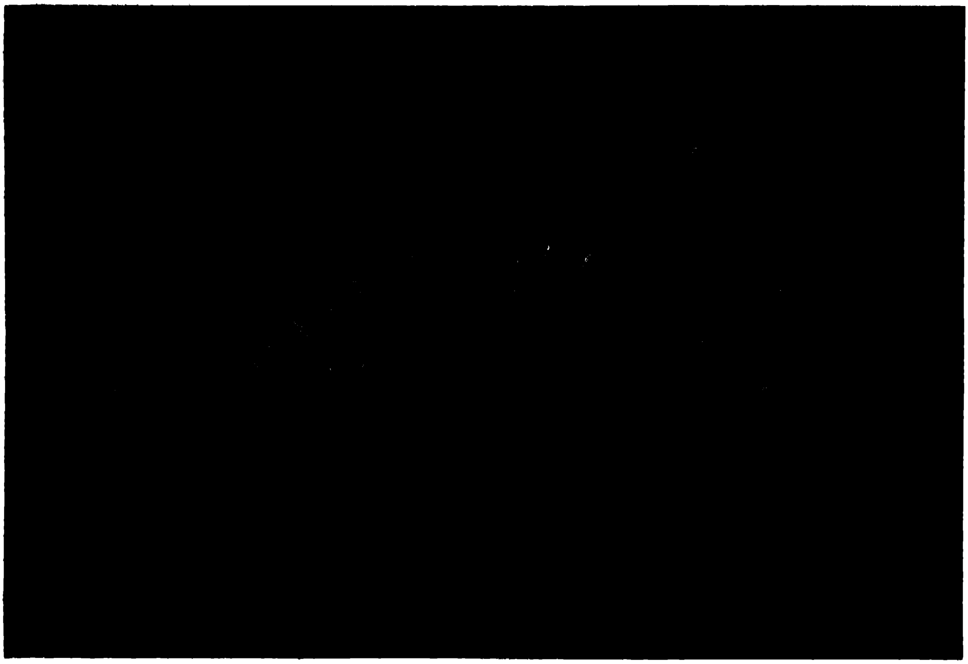


FIG. 6. THE LOWER JAW OF THE BLACK-TIPPED SHARK
THIS IS PHOTOGRAPHED FROM BEHIND AND ABOVE. NOTE THE FRAGMENTS OF VARIOUS STINGAREE SPINES, 12 IN ALL—(11) ADHERENT TO AND (1) EMBEDDED IN THE JAW. SPECIMEN IN THE COLLECTIONS OF THE AMERICAN MUSEUM.

ent to one jaw of a shark of this species. The jaws under study were dissected from a female specimen taken at Sanibel Island, off the west coast of Florida, by Dr. R. C. Murphy, in January, 1919.

On the left lower jaw, about one third of the distance from the symphysis to the angle of the jaw, is the tip of a sting measuring 10 mm long. This is set to point toward the symphysis but downward at an angle of about 45 degrees. This sting was undoubtedly thrust into the tissues covering the jaw when the ray was caught by the shark. In the case of this specimen, as in those described above, the conjecture is allowable that if the dissection of the jaws had been carried on with a view to finding stings, more of these would certainly have been discovered.

THE TIGER SHARK AN EATER OF RAYS

This habit of the tiger shark (*Galeocerdo tigrinus*) has incidentally been known since 1784, when William Andre published an article and a figure in the *Philosophical Transactions of the Royal Society of London.* The last section of this article and the last of his figures were together intended to prove what has been incidentally shown in the last paragraph above—"That the Teeth of Cartilaginous Fishes are Perpetually Renewed." We will let Andre speak for himself.

> Being engaged in dissecting the jaws of a very large shark, I was surprised to find a portion of that sharp, bearded bone found in the tail of the fire-flaire, or sting-ray, driven quite through the lower jaw among the posterior teeth, and fixed almost immoveably. How this happened must be obvious to every one [Fig. 7]. . .

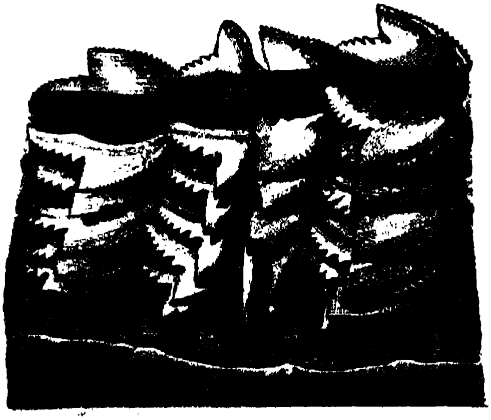
> The sharp bone of the sting-ray was fixed in the lower jaw between two rows of teeth, and at their posterior part, where the first rudiments of the future teeth are formed, and it will be clear to every one, particularly those who are conversant in such matters, that this could not have happened without producing a great deal of pain, swelling and disorder in the part where it was fixed. It is unnecessary to enumerate the different kinds of mischief this might occasion. Let it suffice to observe, that on account of the space taken up by this extraneous body, the teeth on each side of it, for want of room, could never after be perfectly formed. The teeth on the left-side wanting their angles to the right, and the teeth on the right-side being destitute of their angles to the left.
>
> As it is certain, that the anterior teeth were formerly posterior ones, and as the teeth in each row were all deficient in one angle, it follows, that they must have been formed posterior to the insertion of this extraneous body. Again, if we allow that before the accident the animal was in possession of perfect teeth, it follows also, that they were consumed and replaced by imperfect ones.

Of course, in the light of what has been shown as to the multiple attempts of both the hammer-head and the spotted-fin to catch and feed on sting-rays, our author is in error as to the "pain, swelling, and disorder" resulting from the embedding of the sting-ray spine in the jaw of the tiger shark. Nor does he seem to have understood that the tooth bud was divided by the sting so that from the parts have arisen two imperfect right and left halves of what would, but for the sting, have been a normal row of teeth. This is plainly shown in his figure (Fig. 7 herein).

But he does explain how the disturbance caused by the embedding of the "sting" has somehow caused the formation of the divided teeth. He further notes that the normal teeth above the spine have all been replaced and their places taken by abnormal teeth; that since 6 normal teeth have been replaced by 6 abnormal ones, this must have taken place a long time ago. Then he adds, "I have endeavoured to prove that a part of the inhabitants of the great deep retain, in the article of teeth, a perpetual juvenility, being apparently utter strangers to edentulous old age."

Commenting on the succession of teeth in sharks, Richard Owen, in his "Odontography" (p. 39, London, 1840), says that to determine the matter it would be necessary that ". . . a foreign body, *e.g.*, should be inserted into the base of the jaw of the shark, and a tooth in the corresponding place should be so marked, as at a subsequent period it might be recognized, and its position compared with the perforated part of the jaw." Then he rather naïvely adds that "Such an experiment would not be very practicable in the carnivorous inhabitants of the deep we are now considering, but accident has satisfactorily supplied its place." Then Owen goes on to reproduce Andre's figure and account referred to above, without, however, giving Andre any credit.

I have captured a considerable number of tiger sharks and have dissected their jaws, and there is in the American Museum a large collection of such jaws, but none of these contain stings. Dissection of the stomachs of a number of



—After Andre, 1784

FIG. 7. AN EMBEDDED STING-RAY'S SPINE

THIS STING HAS BEEN EMBEDDED IN THE JAW OF A TIGER SHARK (*Galeocerdo tigrinus*) SO LONG THAT THE NORMAL TEETH HAVE DISAPPEARED AND THEIR PLACES HAVE BEEN TAKEN BY ABNORMAL ONES.

FIG. 8. LOWER JAW OF A MACKEREL SHARK

THIS FIGURE MADE FROM ABOVE SHOWS THE RIGHT LOWER JAW OF *Lamna* SP. TO HAVE SUFFERED GREAT INJURY. THE TEETH AND TOOTH BUDS OF ROWS 5 TO 9 INCLUSIVE HAVE BEEN COMPLETELY EXTIRPATED. SPECIMEN IN THE COLLECTIONS OF THE AMERICAN MUSEUM.

tigers (some caught in Florida with sting-ray bait) has brought to light an extraordinary variety of foodstuffs, but no remains of sting-rays. Furthermore, in all my tiger shark fishing at Key West I have never seen a tiger shark trying to catch a sting-ray. However, at least one other man has found the indubitable evidence of such cannibalism.

In July and August, 1920, Mr. J. C. Bell, of the Museum's department of preparation, spent some weeks at Morehead City, North Carolina, as guest of the Ocean Leather Company. His particular errand was to make for the American Museum plaster moulds of sharks and rays, as these fishes were brought in from the net fishery at Cape Lookout. Fortunately, however, Mr. Bell made notes on stomach contents also, and these were later worked up and published by him and Mr. J. T. Nichols. Their article "Notes on the Food of Carolina Sharks" (*Copeia*, No. 92, pp. 17–20, 1921) is of very great value. So also is Mr. Nichols' more popular article, "What Sharks Really Eat," published in *Natural History* (Vol. 21, pp. 272–278, figs., 1921), based in large part on the same data.

Bell and Nichols record three tiger sharks, varying from 10.5 to 11.5 feet in length, taken on August 13. Two of these contained large pieces of the smaller devilfish, *Mobula olfersi*, and the third a part of a whip-tailed ray. Five days later, a large tiger shark was found to contain a large sting-ray cut into three pieces. Another had bitten off and swallowed the head of a *Mobula*. The fact that these sharks had dined on the rays may possibly be due to the fact that they were all cooped up in large nets which took some time to clear, thus giving the sharks time to prey on the rays.

Captain W. E. Young, who has a wide knowledge of these denizens of the deep, has kindly given me certain general accounts of sharks feeding on rays which will now be incorporated herein. He states that:

> Sharks everywhere seem fond of rays and may be found feeding on them. These rays are all provided with from one to five sharp stingers of bone with barbs pointing backward. These stingers inflict terrible wounds on human beings, but though the ray stings the shark when it catches and eats the ray, the stings do not seem to injure the shark. The shark cuts up the ray, and swallows these parts, the tail often being included. Thus the stingers get into the stomach of the shark where I have often found them. Eventually these work out through the wall of the stomach and get into the muscles and work toward the head or the tail according as they are pointed. I have found a sting on the back under the skin and another up near the brain.

At St. Thomas he witnessed an attack by a shark on a ray, which he describes as follows: "The shark found the ray in the corner of the boat landing. After sparring for an opening the shark darted in, caught the ray in its mouth, and made off into the deep water. The ray put up a good fight but its sting was no match for the teeth of the shark."

He also states that while at Anegada, British West Indies, a ray was caught in one of his nets. It was left therein for some time, whereupon a tiger shark endeavored to eat it and was itself entangled in the net.

The largest of the rays is the gigantic *Manta*, which may reach the extreme width of 25 feet, but which is perfectly harmless and, lacking a spine, defenseless. Captain Young caught many of these at Warimos Island in Djibuti Harbor, French Somaliland. A considerable number of these mantas had had their fins bitten by sharks. However, the *Manta* is such a gigantic ray that even a large ray could hardly do more than take some bites out of its great pectoral fins.

SHARKS PREYING ON OTHER SHARKS

It is generally known that if a shark is caught on a hook, hauled on board a

FIG. 9. THE RIGHT LOWER JAW OF A MACKEREL SHARK

THIS SHOWS THAT A WHOLE SECTION OF THE CARTILAGE OF THE JAW HAS BEEN TORN OUT, BUT HAS BEEN LARGELY REPLACED THROUGH REGENERATION. SPECIMEN IN COLLECTIONS OF THE AMERICAN MUSEUM.

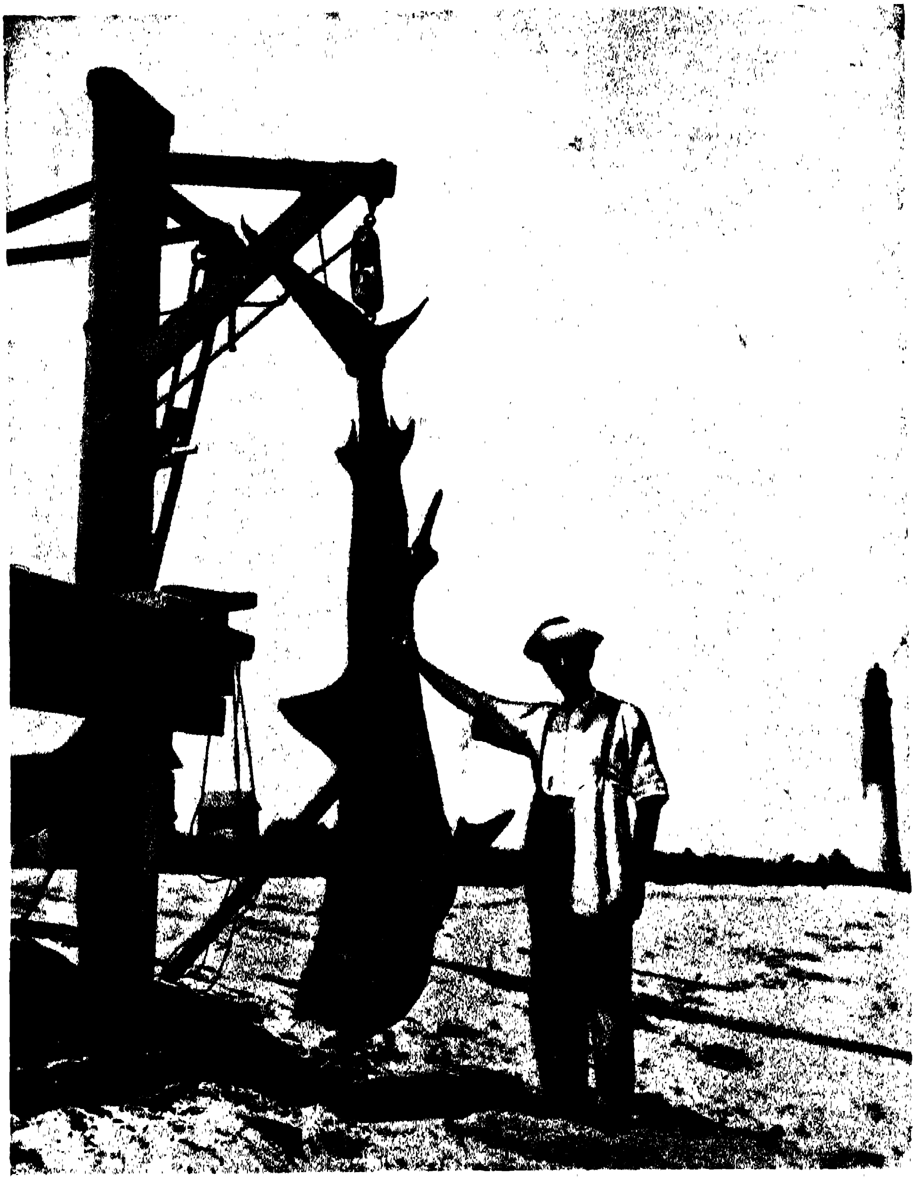


FIG. 10. A LARGE TIGER SHARK

THIS SPECIMEN OF *Galeocerdo tigrinus* IS SWUNG BY THE TAIL TO THE CRANE ON THE WHARF AT THE LABORATORY OF THE CARNEGIE INSTITUTION OF WASHINGTON AT LOGGERHEAD KEY IN THE DRY TORTUGAS, FLORIDA. NOTE THE PARTLY EVERTED GULLET DISCHARGING THE FEATHERS OF A WATER BIRD.

boat, chopped up with an axe and thrown overboard, it will be devoured by other sharks. Also it is a matter of common knowledge that, around a whale being "cut in" if one of the sharks scrambling for tidbits is disabled by a whaleman's spade, it will be speedily devoured by its companions.

A vivid general account of shark-eat-shark has recently been given by Dr. C. H. Townsend, director of the New York Aquarium, in the *Bulletin of the New York Zoological Society* (Vol. 34, p. 163, 1931). While on the *Albatross* off the Bahamas some years ago, Townsend saw the vessel surrounded by a great many sharks. Nearly a dozen were captured, cut open and thrown back into the sea. "The sharks, attracted by the bloody carcasses gradually being thrown overboard, provided an exhibition of how hungry sharks behave in the presence of an unexpected supply of food [in the shape of dead sharks]."

There is in the collections of the American Museum a badly mangled jaw of a mackerel shark (*Lamna sp.*) of unknown source. As may be seen in Figs. 8 and 9 the right lower jaw has been seized (no other marine animal than a shark with like strong front teeth could have done this), and the jaw with the tooth buds Nos. 5, 6, 7, 8 and 9 has been torn out. The cartilage of the jaw has by regeneration filled in, from sides and bottom, the torn-out cartilage of the jaw, but the tooth buds totally extirpated make impossible any regeneration of the missing teeth.

However, definite accounts by scientific men of this feeding by definitely named sharks are few and far between. I have found but four, and these accounts will now be set out under the name of the shark that we may have definite knowledge of cannibalism by certain particular sharks.

THE TIGER SHARK A CANNIBAL

This shark (whose scientific name, as we have seen, is *Galeocerdo tigrinus*) is definitely known to be a cannibal. Our first direct knowledge that this shark will feed on its fellows we owe to Lewis Radcliffe. In his "Sharks and Rays of Beaufort, North Carolina" (*Bulletin U. S. Bureau of Fisheries*, Vol. 34, p. 263, 1916), there is a very realistic account of this cannibalism. A tiger, 10 feet, 1 inch in length (one of three already captured) has been suspended from a boom with its head out of water. Subsequent events Radcliffe describes as follows:

> About this time a shark, larger than any of those taken, swam up to the one hanging from the boom, and raising its head partly out of the water, seized the dead shark by the throat. As it did so, the captain of the *Fish Hawk* began shooting at it, with a 32-caliber revolver, as rapidly as he could take aim. The shots seemed only to infuriate the shark, and it shook the dead one so viciously as to make it seem doubtful whether the boom would withstand its onslaught. Finally it tore a very large section of the unfortunate's belly, tearing out and devouring the whole liver, leaving a gaping hole across the entire width of the body large enough to permit a small child to easily enter the body cavity. At this instant one of the bullets struck a vital spot, and after a lively struggle on the part of the launch's crew, a rope was secured around its tail. The four specimens, all females, were brought to the laboratory for examination. The last shark was 365.8 cm (12 feet) in length, and the liver of the smaller one was still in its stomach, the estimated weight of which was 40 pounds. At the time of capture one of the sharks regurgitated a rat, another a small shark about 61 cm in length.

Of the tiger shark, Coles writes (*Copeia*, 1919) that in June–July, 1918, he found in the stomachs of three small tiger sharks at Cape Lookout, North Carolina, "cleanly bitten pieces of freshly eaten shark meat with the skin attached, just as if the chunk of meat had been cut from the side of a shark." Again on June 25, from a 7-foot, 9-inch specimen, he obtained "eleven chunks of shark meat of from one to five pounds in weight." These he says were torn from hammer-headed, sharp-nosed and ground sharks. That these pieces were shark flesh was of course easily ascertained, but only microscopical examina-

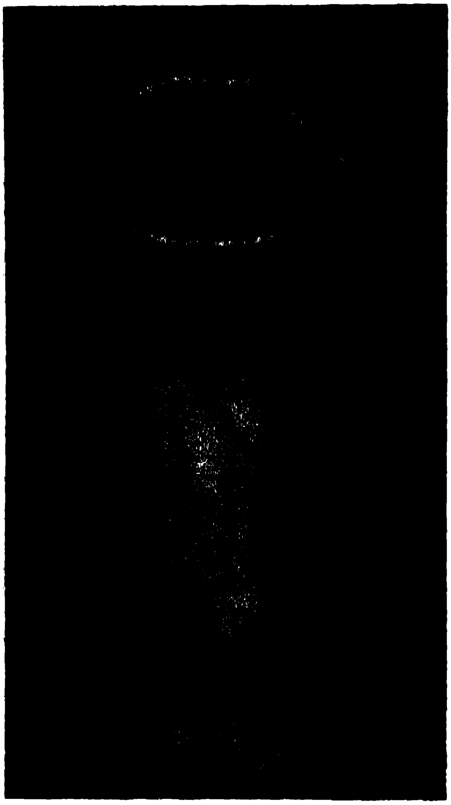


FIG. 11. THE JAWS OF A LARGE TIGER SHARK

FOR COMPARISON A 12-YEAR-OLD BOY HOLDS AND LOOKS THROUGH THESE. NOTE THE HUGE GAPE AND THE LARGE SICKLE-SHAPED CHOPPING TEETH.

tion of the denticles would give diagnoses of genera and species.

From the same locality, in July–August, 1920, Bell and Nichols (*Copeia,* pp. 18–19, 1921), report stomach contents of tiger sharks as follows. On July 9, a *Galeocerdo,* 11 feet, 3 inches long, contained "a large piece from the side of the head and gills of an 11-foot hammer-head taken in the same net with it." On July 13, the stomachs of four tigers contained large pieces (some of them equal to half of the shark) of the black-tipped shark (*Carcharhinus limbatus*). Two 10-footers, on July 16, contained three or four young hammer-heads. On July 31, a 12-foot, 2-inch tiger (weight 630 pounds) "contained a large shark [kind undetermined] of about eight or nine feet bitten in seven or eight pieces." An 11-foot male (450 pounds) captured on August 5, "contained a small hammer-head of about 3.5 feet intact, and several parts of other sharks." On the same day, two females of 9 feet, 10 inches, and 11 feet, 6 inches, contained small pieces of shark, probably a black-tip.[1]

Captain Young informs me that while net-fishing for sharks at Port Stephens, New South Wales, Australia, he got a large tiger shark with the belly and sides badly torn. When the net was cleared the last shark was a tiger. When this was made fast by the tail and hauled up by the derrick on the wharf, it disgorged through the mouth a great mass of skin, fin, liver and intestines. All these were easily identified as having come from the first tiger captured. Again near Fernandina, Florida, a female tiger shark was caught, and, when hauled up by the tail, disgorged three large sections of tiger shark meat (easily identified by the stripes) and a lot of feathers from a water-fowl.

The gullet of the tiger shark, like that of many other sharks, is merely a large passageway connecting the huge mouth and the capacious stomach. When the shark is hung up by the tail the gullet tends to become everted and the stomach evacuates through this any large undigested material. This may be seen in Fig. 10, which shows such a tiger shark which I captured at the Dry Tortugas, Florida, years ago.

CANNIBALISM AMONG HAMMER-HEADS

The hammer-head (*Sphyrna zygaena* by name), portrayed in Fig. 1, and in the preceding section shown to be a victim of the tiger shark, is also a straight cannibal. This was first reported by Coles (1910), who writes as follows of a 13-foot, 10-inch female specimen captured at Cape Lookout in July, 1918:

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[1] Much of this data may also be found in Nichols' article in *Natural History,* Vol. 21, pp. 272–278, 1921.

> At the time of her capture, she had just eaten four of her own species from my net, two of which had been swallowed whole, except the heads of the five-foot examples, and there were four cleanly cut pieces, which represented entire bodies except heads, of two or more hammer-head sharks; then the stomach contained more than a peck of vertebrae of sharks, provisionally identified [?] as her own species.

THE CUB SHARK ALSO A CANNIBAL

For this shark (*Carcharhinus commersonii*) cannibalistic habits similar to those in the tiger are reported by Bell and Nichols (1921). On July 13, 1920, two were taken which had fed on smaller black-tipped sharks (*Carcharhinus limbatus*). None others, however, contained shark flesh, the food mainly being various bony fishes.

THE MACKEREL SHARK A SHARK-EATER

I have on pages 412, 413 (Figs. 8 and 9) and 415 figured and described a jaw of this shark which had been torn by another shark. That the European form, *Lamna cornubica*, a fierce and ravenous shark, also feeds on other sharks is attested by Couch (1867, p. 43) who notes that he found in the stomachs of various specimens the skeletal remains of cartilaginous fishes. And Day (1884, p. 298) expressly states that in the stomach of an 8-foot female taken at Mevagissey, southern Cornish coast, in 1881, there was found a large partially digested dogfish.

MISCELLANEOUS ACCOUNTS OF CANNIBAL SHARKS

A careful search through the literature would undoubtedly bring to light many miscellaneous notes on this subject. I have chanced upon three which may be added for completeness' sake. Couch (1867, p. 29) states that from the stomach of a blue shark (*Prionace glauca*) he once took a large piked dogfish bitten across the middle into two pieces. Of the spinous shark, *Echinorhinus spinosus*, John Gatcombe states (*Zoologist*, Vol. 35, p. 108, 1877), that one captured off Plymouth, England, in that year contained four piked dogfish. And Day (p. 324, 1880), carries the story further by recording that a specimen of the spinous shark, taken off the Eddystone Light in 1869, had in its stomach "several dog-fishes, some 3 feet in length." Since these dogfishes are a great nuisance to the commercial fisherman, these enemies of theirs must be credited as friends of the fishermen.

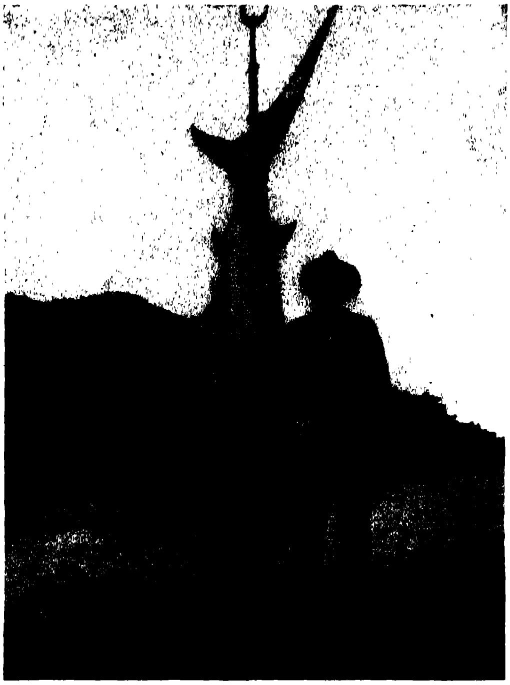
CANNIBALISTIC PRACTICES BY UNIDENTIFIED SHARKS

Heretofore the data concerning these practices among elasmobranchs has been set out under the name of the aggressor. That now to be presented concerns cases in which the victim in some cases is known, but in none is the predator known.

—*Photograph by courtesy of Capt. W. E. Young*

FIG. 12. THE RESULTS OF CANNIBALISM

THIS TIGER SHARK WAS CAUGHT IN A NET AND WHILE HELD THERE WAS PARTIALLY DEVOURED BY OTHER SHARKS.



—*Photograph by courtesy of Capt. W. E. Young*

FIG. 13. A VICTIM OF CANNIBAL SHARKS

THIS HAMMER-HEADED SHARK (*Sphyrna zygaena*) FIGURED HERE WAS CAUGHT IN A NET AND BADLY TORN BY OTHER SHARKS.

My sole experience of shark-eat-shark is as follows. While at the Tortugas Laboratory of the Carnegie Institution of Washington in 1914, on the afternoon of July 14, I set a shark hook buoyed to an empty five-gallon oil-can off our dock on the west side of Loggerhead Key. Shortly after daylight the next morning the can was seen to be violently agitated and the back and tail fin of a large but unidentified shark were observed near it. Since the cook's wife was with him and since the mess house was between the dormitory and the dock, it was impossible to go for the shark in ordinary Tortugas costume. But as soon as I could throw on some clothes I hurried out to the hook and found the head and neck parts of a short-nosed shark, *Hypoprion brevirostris,* everything from the pectoral fins backward being *gone.* An inquest was held over the remains, and the shark was identified as above. The shark which had been seen had evidently eaten his fellow. The commotion in the water had plainly been caused by the attack of the one shark and the efforts to escape of the other. The hooked shark was at a terrible disadvantage and could do nothing but flounder about. Unfortunately, the marauder was never taken.

Captain Young had a similar experience once. On overrunning his hooks at Anegada, British West Indies, one morning he found on one the head only of a dusky shark, which he estimated would have weighed about 250 pounds. The whole body from tail to gills had been eaten by other sharks.

My own experiences of shark-eat-shark cannibalism are unfortunately confined to the case above set out, but from the extensive notes made by Captain Young I am privileged to extract the following general data and make them available for the reader. The first case illustrates the voracity of the shark and its insensibility to pain.

At Water Island, one of the Virgin group, West Indies, in 1928, a tiger shark was hooked, but after a hard fight broke away with a torn jaw. The next morning this same shark with the torn jaw was found on one of the hooks badly eaten by other sharks. This shark is shown in Fig. 12, where it is seen that the whole side had been torn away from gills to the end of the abdominal cavity and practically all the internal organs had been eaten, also the pectoral fin had been torn away.

A hammer-head was taken in a net at Frenchman's Cape, Virgin Islands, in 1928. Caught in the net almost always by the peculiar hammer-shaped head, the remainder of the body is generally clear and especially tempting for attack by other sharks. How this shark was "mauled" by other sharks may be seen in Fig. 13. Note that it is the abdomen which is always attacked first. This is softer, and allows the marauder to get a firmer bite than any other part of the victim. However, other parts may be taken if competition is great. Thus Captain Young found in a shark's stomach opened at Morehead City, North Carolina, the whole tail of a large shark.

These records plainly justify the accusation of cannibalism against sharks, but in some cases this cannibalism was made easy by the fact that all these sharks (save Radcliffe's) were cooped up in the narrow confines of a net. In the open the tigers and the other sharks would have had difficulty in catching these other sharks. In the net either voracity or panic, or both, would lead to the attacks with the results noted. These bitings are facilitated for the tiger by the fact that it particularly has a mouth of huge gape beset with many large, sharp, sickle-shaped, chopping teeth. Such a jaw is shown in Fig. 11.

CANNIBALISM AMONG RAYS

This little section must be added, for unexpectedly and almost unbelievably accounts have been found which justify this addendum. I say "almost unbelievably" because ordinary rays have relatively very small mouths filled with comparatively small and non-biting teeth used for crushing crustacean and other relatively soft-bodied food. However, in the pavement-toothed rays, their mill-like teeth are used for crushing the shells of the oysters and clams which constitute their chief food. That rays should prey on other rays seems preposterous. But here follow the statements of some of the most distinguished English ichthyologists.

Raia batis a Cannibal

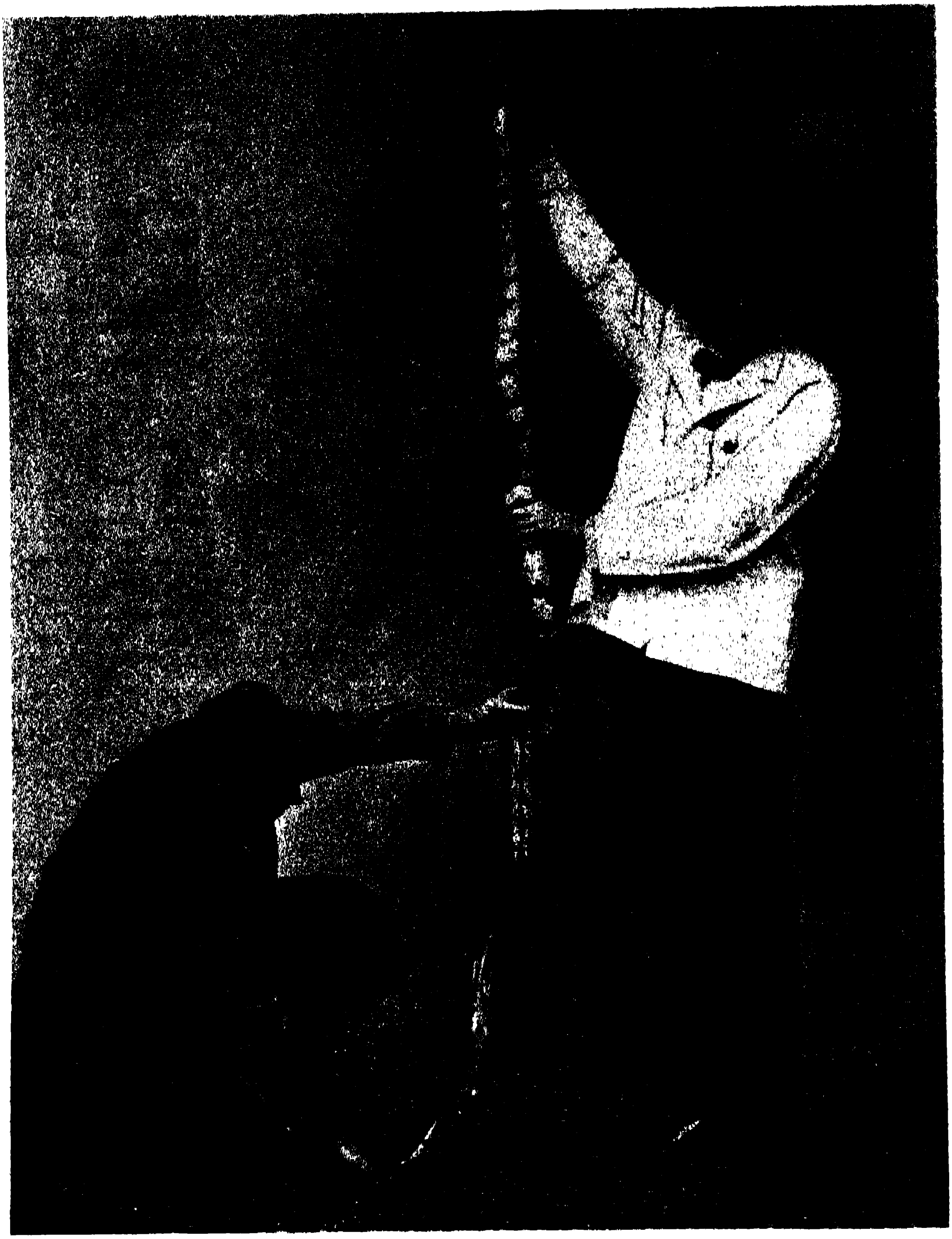
The common English skate, *Raia batis,* is the only ray, so far as I know, to have such cannibalistic habits attributed to it. Of this ray Francis Day, in his "Fishes of Great Britain and Ireland" (Vol. 1, p. 337, London, 1880), says that a specimen five feet wide was exhibited at Gravesend in December, 1881, which had in it a small skate and a dogfish two feet long together with a lobster. He apparently was an eye-witness in this case.

Of this same habit in this same ray, Jonathan Couch says in his "History of the Fishes of the British Islands" (p. 88, London, 1867) that he dissected several and that in the stomach of one (size not given) he found a "thornback ray about eighteen inches in length."

Lastly, of this same ray, we read in Wm. Thompson's "Natural History of Ireland" (p. 259, London, 1856) of the capture on the north coast of Ireland of a huge specimen 5 feet, 8 inches wide; 7 feet, 3 inches long; and weighing 224 pounds. Its capture was effected thus: "A small skate got meshed [in a net] and was swallowed with a piece of the trammel of the net by the large one; and [the latter] being thus entangled [and held by the swallowed net] . . . was easily secured by the fishermen."

Thus then ends the tale, so far as the data are at hand, of cannibalism among the elasmobranchs. Fuller investigation of the records would undoubtedly bring to light other cases. However, I have taken my own observations and have added to them those which have readily come to my hand.

With regard to sharks feeding on rays, it is too much to say that these specialized elasmobranchs constitute the steady diet of hammer-heads, black-tips and tigers, but it is certain that they constitute the *pièce de resistance* of the two particular sharks first studied, as is plainly indicated by the number of sting-ray stings found in their jaws and attached tissues. For the other sharks, it is clear that under favorable conditions (restricted space especially) they are plainly cannibalistic, and are far more dangerous to their kinsmen than to the genus *Homo.*



A LIVE EIGHT-FOOT PYTHON, WEIGHING TWELVE POUNDS, BEING HELD BY DR. FRANCIS G. BENEDICT

MANY ANIMALS, BOTH WARM- AND COLD-BLOODED, HAVE BEEN STUDIED IN THE NUTRITION LABORATORY OF CARNEGIE INSTITUTION IN THE EFFORT TO INTERPRET PHENOMENA IN HUMAN PHYSIOLOGY, PARTICULARLY PHENOMENA RELATING TO HEAT PRODUCTION, HEAT LOSS, HEAT REGULATION, AND BODY TEMPERATURE.

REPTILES USED IN STUDY OF HUMAN PHYSIOLOGY[1]

By Dr. **FRANCIS G. BENEDICT**
DIRECTOR, NUTRITION LABORATORY OF CARNEGIE INSTITUTION OF WASHINGTON

SINCE the day when our first parents tasted the fruit of the Tree of Knowledge and the serpent was condemned to crawl on the ground on its belly, loathed by man and crushed under foot, the snake has been almost universally abhorred. This feeling of repugnance for the snake persists with many of us even to-day, in spite of the fact that this animal now serves many useful purposes. Thus, certain snakes such as the gopher snakes are of real economic importance in some localities because of their activity in destroying rodents, and snakes' skins are becoming more and more popular for trimmings on shoes and purses.

When we summon a physician to the house or consult him at his office, we do not stop to realize that many a lowly animal, such as the snake, has indirectly contributed its small share to the learning possessed by the physician. In order to diagnose our ailment correctly and prescribe treatment intelligently, the physician must have knowledge first of all concerning the physiological processes that take place in the body when we are well and healthy.

For this reason laboratories of research were established, where physiologists have been trying to discover what are the normal reactions and the normal functions of man. Each individual organ and each anatomical part of the human body has been studied under normal conditions, in the attempt to secure all the information possible pertaining to that particular function. The study of the diseased body, or the study of human pathology, has likewise been carried on as an indirect method of obtaining knowledge regarding normal human physiology. Thus, information regarding the abnormal liver of man in disease has proved of great value in securing more exact knowledge of the normal function of the liver.

Another indirect means of understanding the functions of the human body is the study of animal physiology. Many observations have been made with different animals, the object of most of which has been the ultimate perfection of knowledge regarding the physiology of our own bodies. In some animals the particular organ or function in which the medical man or scientist may be interested is especially elaborated. The digestive organs of the ruminant, for instance, are so elaborate that the food remains in the alimentary tract for a much longer time than is the case with man. This longer retention of the food results in fermentations and chemical reactions, the study of which helps in interpreting certain digestive processes in man.

In studying animals to clarify the problems encountered with humans, scientists recognized years ago the value of including cold-blooded animals. It has been found that the best indications as to whether our body is functioning normally are our heat production and our body temperature. The amount of heat that we produce and our body temperature show whether our vital activity or our life processes are at a normal or an abnormal level. To aid in the inter-

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[1] A monographic report covering the details of this investigation is now in press. It will appear under the title: "The Physiology of Large Reptiles, With Special Reference to the Heat Production of Snakes, Tortoises, Lizards and Alligators." It will be listed as Publication No. 425 of the Carnegie Institution monographic series. This article has been prepared by Miss Elsie A. Wilson, of the staff of the Nutrition Laboratory.

MEASURING THE LENGTH OF A SEVENTEEN-FOOT PYTHON WEIGHING SEVENTY POUNDS

PHOTOGRAPH TAKEN BY MR. E. R. SANBORN IN THE REPTILE HOUSE AT THE NEW YORK ZOOLOGICAL PARK.

pretation of the abnormally high temperature of man during fever it was early thought expedient by investigators to note the effect of rapidly changing body temperatures in the case of cold-blooded animals. The body temperature of the cold-blooded animal changes with the temperature of the air surrounding it.

How do these changes in the body temperature of the cold-blooded animal affect its body and how can a study of these changes aid in understanding the cause and results of fever in man? These are questions typical of those that are continually presenting themselves to the medical man and the research worker. Some of them have now been answered. Others remain yet to be solved. But there is no doubt that the study of animal physiology is necessary for the best understanding of human physiology.

In 1907 the Nutrition Laboratory was established in Boston by the Carnegie Institution of Washington, for the study of problems in human and animal nutrition. Since its establishment, the Nutritional Laboratory has undertaken an extensive program of research on heat production and thermal relationships, not only with humans but with a large number of other warm-blooded animals ranging in size from an 800-kg. horse to a 22-gram mouse. In the furtherance of this program the heat production of cold-blooded animals under various conditions has likewise been studied.

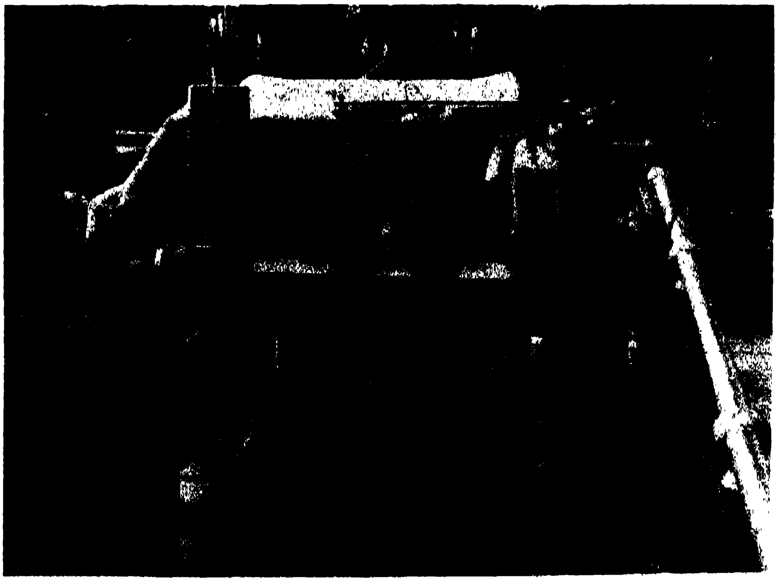
The first experiments carried out by the Nutrition Laboratory with cold-blooded animals began in 1915 at the New York Zoological Park and continued over a period of 17 years. Nearly one thousand observations were made, chiefly with snakes but also with a number of lizards, alligators and giant tortoises. Thirty-six snakes were used which varied in size from a 5-pound gopher snake to a 17-foot reticulated python of 70 pounds.

The accompanying photographs give an approximate idea of the size of some of the larger snakes. The 17-foot python had to be held by five men in order to obtain measurements of its length and body girths. A 9-pound and 120-pound alligator, 8 lizards, weighing about 2 pounds each, and 9 tortoises, weighing from 10 to 300 pounds, were also studied. Most of these animals were obtained at the New York Zoological Park through the courtesy of the curator of reptiles, Dr. Raymond L. Ditmars.

The main object of our study with these animals was to measure the heat production and the body temperature under various conditions, and to compare the results with similar observations on humans and other warm-blooded animals. Many other observations were likewise made regarding changes in body weight, the heart rate, the respiration rate, the water vaporized from the body, and the composition of the urine and feces.

Since it was known from previous experimental work that the heat production can be most readily determined not by direct measurement but by indirect measurement of the products of respiration, an apparatus was installed in the reptile house of the New York Zoological Park in which the carbon dioxide exhaled and the oxygen absorbed by the snake or other reptile could be accurately measured during a definite period of time.

In addition to the study of the heat production, another problem was to establish the relationship between the body temperature and the environmental temperature of these animals. Seemingly it should be simple to establish this relationship but, as a matter of fact, it proved to be most difficult. The temperature of the animal itself could



THE APPARATUS

USED BY THE NUTRITION LABORATORY AT THE NEW YORK ZOOLOGICAL PARK TO STUDY THE HEAT PRODUCTION OF SNAKES AND OTHER REPTILES. THE SNAKE IS PLACED IN AN AIR-TIGHT, WELL-VENTILATED BOX, SHOWN BACK OF THE TABLE, COVERED WITH A QUILT. THE BLOWER UNDER THE TABLE DRAWS THE AIR FROM THE CHAMBER, PASSES IT THROUGH THE REAGENT BOTTLES ON TOP OF THE TABLE, WHERE THE CARBON DIOXIDE AND WATER VAPOR ELIMINATED BY THE SNAKE ARE REMOVED FROM THE AIR, AND RETURNS IT TO THE CHAMBER, ENRICHED WITH OXYGEN TO REPLACE THAT USED BY THE SNAKE. THE INCREASES IN WEIGHT OF THE VARIOUS REAGENT BOTTLES (WHICH ARE WEIGHED ON THE BALANCE IN THE REAR) SHOW THE AMOUNT OF CARBON DIOXIDE EXHALED AND WATER VAPOR ELIMINATED BY THE ANIMAL.

MEASURING THE SKIN TEMPERATURE OF A LARGE PYTHON

AT THE NEW YORK ZOOLOGICAL PARK WITH AN ELECTRIC THERMOMETER. WHEREAS THE BODY TEMPERATURE OF MAN AND PRACTICALLY ALL WARM-BLOODED ANIMALS REMAINS ESSENTIALLY UNCHANGED REGARDLESS OF OUTSIDE TEMPERATURE, THAT OF COLD-BLOODED ANIMALS IS AFFECTED BY THE TEMPERATURE OF THEIR SURROUNDINGS.

be accurately determined by noting the temperature in the mouth or the cloaca, but the exact temperature of the air surrounding the animal was not so easily found. For this reason mercurial thermometers were not used in our most exact studies, but, instead, a sensitive electric device, whereby the temperature of the skin of the snake and the temperature of the air around the snake could be recorded within a few seconds.

In the accompanying picture we see a man at the door of the snake den in the New York Zoological Park, holding in his hand a light bamboo pole, at the end of which is a so-called "thermo-junction" or electric thermometer. This electric thermometer is connected by wires to another electric device (galvanometer) in the room outside the den. The electric thermometer was carefully placed between the folds of the snake, and the temperature of the skin at that spot was instantly recorded on the apparatus outside.

Fifteen seconds after this particular photograph was taken, this huge snake (a python) made a lunge at an observer at the front of the den, striking its head against the plate glass at the front of the cage but fortunately missing the man. Many of these snakes are highly irritable and dangerous to handle.

The body temperature of man and practically all warm-blooded animals remains essentially constant under normal conditions, regardless of what the environmental temperature may be. In the cold weather of the Arctic zone, for example, the body temperature of the warm-blooded animal is no lower than it is in the temperate zone or the tropics. Indeed, the polar fox is known to have a body temperature even higher than that of man. The temperature of the cold-blooded animal, on the other hand, is affected by the temperature of its surroundings.

Thus, the Nutrition Laboratory found that the body or the cell temperature of the snake changes with almost mathematical regularity with the changes in room temperature. It has been supposed that the cold-blooded animal has a temperature a little *above* its environment, but our observations prove conclusively that the temperature of the snake is usually a little below that of the environment.

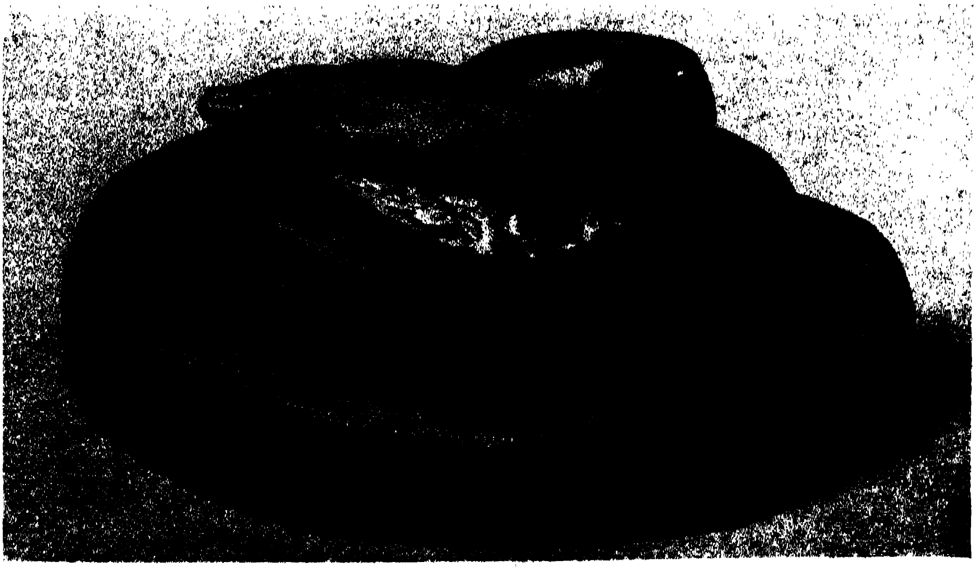
It was likewise found that the snake loses a great deal of water from its skin and lungs. This water, in vaporizing, absorbs heat. The total amount of heat produced by the snake is usually so small that all of it is lost in the vaporization of water. In many instances heat may be absorbed by the animal from the environment, as it suns itself. This absorbed heat serves to vaporize still more water.

Under ordinary circumstances the quiet snake, not in active digestion, will have a temperature only a degree below the average temperature of the environment. At the peak of digestion there may be a slight elevation of its temperature. If the snake is agitated or has been extremely active, its temperature may be 9° or 10° F. above the temperature of the environment but within a few hours will fall to the temperature of the environment or somewhat below it.

One of the most interesting features of our temperature study was with an incubating snake. The majority of snakes are viviparous, some are oviparous, and of these one is known to cover her eggs with her body. It has long been a matter of debate as to whether this covering of the eggs by the mother snake is primarily to protect the eggs or to aid in the incubation.

In April, 1931, a South African python laid 20 eggs at the National Zoological Park in Washington, D. C., coiled about them in the characteristic manner, and remained there for approximately 60 days. Unfortunately the eggs were not fertile and hence did not hatch. The Nutrition Laboratory was privileged to study the skin temperature of this animal while she was on her eggs.

Extreme care was taken to establish the true temperature of the air surrounding the snake, indeed even greater



AN AFRICAN PYTHON GUARDING HER EGGS

A FEMALE AFRICAN PYTHON AT THE NATIONAL ZOOLOGICAL PARK IN WASHINGTON, D. C., COILED AROUND A CLUTCH OF TWENTY EGGS. SHE REMAINED IN THIS POSITION FOR SIXTY DAYS BUT THE EGGS WERE NOT FERTILE AND DID NOT HATCH. SCIENTISTS HAVE BEEN IN DOUBT WHETHER THE MOTHER COVERS THE EGGS FOR PROTECTION OR FOR INCUBATION. CAREFUL MEASUREMENTS SHOWED THE TEMPERATURE OF THE AIR SURROUNDING THE SNAKE TO BE 86° F. WHILE THAT OF ITS BODY WAS 93° F. APPARENTLY THE MOTHER-SNAKE WAS PRODUCING HEAT TO KEEP HER EGGS WARM.

care than was taken to note the temperature of the snake itself. It was clearly demonstrated that the body temperature of this snake was on the whole about 7° F. above that of the air surrounding her. The snake was placid and tractable during the observations, and hence the measurements were uncontaminated by any irritability, excitation or muscular activity, which of themselves would increase her temperature. It thus appears clear that this snake's temperature actually was above that of the environment, and seemingly she was producing heat to keep her eggs warm.

The cold-blooded animal's body temperature and heat production increase and decrease with the rise and fall of the temperature of the air around it. For the most part the cold-blooded animal is quiet in comparison with the warm-blooded animal. At low temperatures especially it engages in little muscular activity, and its vital activity is at a very low level. During periods of dormancy or hibernation its heat production reaches an almost immeasurably low level. It therefore needs very little food, compared with the warm-blooded animal. Yet the large serpents often eat an enormous meal at one time. Thus, during our study, a 70-pound python ate a 20-pound pig. In other words, at one meal it ate 400 times its daily energy needs or enough to last it a year.

In the wild the snake travels a relatively short distance to some water hole, where it waits until its prey comes along. The attack is immediate, and for perhaps 20 minutes the activity is vigorous. At the end of this time the prey has usually not only been killed but is completely swallowed. The snake now has enough food to meet its needs for possibly several months, and has used up very little energy in obtaining it. With no other animals in the world, certainly among the vertebrates, can one expect such economy in the securing of food. In view of this economy in energy expenditure, one can easily understand why it is possible for a large snake to exist for a year or longer without food.

With warm-blooded animals it has been found that, in general, the larger the animal the larger the total heat production. This relationship, however, is not directly proportional to the size of the animal. Thus, a dog weighing twice as much as another dog will not produce twice the amount of heat; nor will a bird three times as large as another produce three times as much heat.

It was thought many years ago that the production of heat is determined by the possibility for losing heat, that is, by the surface area of the animal. Therefore, it was believed that the heat production is proportional to the surface area and that all animals produce the same amount of heat per unit of surface area. With the warm-blooded animals studied by the Nutrition Laboratory it was quickly found that this is not true, but that there is a considerable difference in the heat production per unit of surface area.

Among the cold-blooded animals, as is to be expected, the larger animals also produce the greater amount of heat. But here again the total heat production is not directly proportional to the body weight, for the smaller animals (as with the smaller warm-blooded animals) produce a larger amount of heat per unit of weight than do the larger animals.

On the other hand, the heat production per unit of surface area was for all the cold-blooded animals that we studied, other than the tortoise, reasonably constant at a constant temperature. In such comparisons with cold-blooded animals the temperature has to be taken into consideration as well as differences in surface area, because the heat production varies with the changes in temperature.

The above comparisons are perhaps of

MEASURING THE SKIN TEMPERATURE OF THE INCUBATING PYTHON SHOWN IN THE PRECEDING PICTURE. THE SNAKE WAS PLACID AND TRACTABLE DURING THE OBSERVATIONS, HENCE THE MEASUREMENTS WERE NOT AFFECTED BY IRRITABILITY, EXCITATION, OR MUSCULAR ACTIVITY WHICH OF THEMSELVES WOULD HAVE INCREASED HER TEMPERATURE.

more special interest to the physiologist than to the general reader. We are more particularly concerned in learning how observations on the snake, the lizard, the alligator or the tortoise can help to solve the problems that are found in human physiology. For this purpose we must compare the cold-blooded with the warm-blooded animal, preferably choosing two animals of the same weight. How does the heat production of two such animals of the same weight compare?

In order to make such a comparison both animals must have the same body temperature. It is practically impossible to lower very much the temperature of the warm-blooded animal under normal conditions. Only those animals that hibernate have a variable temperature, and such animals are difficult to secure for study. On the other hand, it is possible to warm the body of certain cold-blooded animals, especially the tropical animals, so that their cell temperature will be essentially that of the warm-blooded animal, that is, about 98.6° F. This was done with a number of snakes, both small and large, and it was found that the cold-blooded animal, even at the same temperature as the warm-blooded animal and weighing the same, can not produce the same amount of heat that the warm-blooded organism produces.

The Nutrition Laboratory has found that the mouse, for example, one of the smallest mammals, produces 640 calories for each square meter of its surface area under normal conditions, without muscular activity, and at an environmental temperature of 82° F. The snake, on the contrary, even when it has the same body temperature as the mouse, can produce at the most only about 100 calories for each square meter of surface area. There is thus a tremendous difference in the thermal relationships shown by these two types of animal.

In this gap between cold-blooded and warm-blooded animals three striking intermediary steps have been noted, further study of which will probably throw much light upon the pronounced differences between cold-blooded and warm-blooded animals.

The female python, for instance, has a body temperature actually higher than its environment during the incubation period. It will be interesting to determine what its heat production is during this period and whether it approximates that of warm-blooded animals any more closely than does that of the non-incubating snake.

The tortoises likewise furnish a field for further study. They have a much higher heat production for each square meter of surface area than do the snakes, alligators and lizards. They also have a much richer blood supply than these other cold-blooded creatures, but even then the blood supply of the tortoise is too feeble to enable it to produce heat at the same rate as the warm-blooded animal. Nevertheless, it can produce more heat than the snake, lizard and alligator, and hence may be considered to occupy an intermediary stage between these animals and the warm-blooded.

The hibernating animal likewise represents an intermediary stage. During hibernation the warm-blooded animal's body temperature and vital activity are greatly lowered. Indeed, the body temperature of a hibernating warm-blooded animal may easily be the same as that of the snake, alligator or fish, for its temperature will fall with that of the environment nearly down to the freezing point of water without resulting in the death of the animal. It is therefore possible to compare the heat production of a hibernating marmot, for example, with that of a lizard of the same body weight and the same body or cell temperature.

A study with hibernating woodchucks is now in progress at the Nutrition Laboratory, but is not yet completed. Thus far the results are in full harmony with several studies of this type by other investigators, who have shown that the marmot even at the same cell temperature as the snake has a much higher heat production. Here again the animal having the richer blood supply and better blood distribution has the larger heat production and is living at a higher level of vital activity, even though its body temperature is greatly depressed. Such variations in body temperature as are found with the hibernating marmot and with the snake, alligator and lizard in the normal course of their existence are not found with humans.

A certain amount of fluctuation in the body temperature of humans does take place, however, especially under the abnormal conditions resulting in fever. Therefore, it is of direct value, in interpreting the laws governing the heat production and heat loss of humans, to study animals showing such marked changes in heat production and body temperature as the incubating python, the red-fleshed tortoise and the hibernating marmot. When such studies are completed, we may hope to be able to solve some of the still unanswered problems in human physiology.

RELATION OF GEOLOGY TO OCEANOGRAPHY[1]

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INTRODUCTION

It is not known what proportion of the sedimentary rocks were deposited under oceanic conditions, but it is believed that a fair estimate of those exposed on the continents would assign at least 60 per cent. to a marine origin. An additional percentage of at least 20 was deposited on land in such close association to marine conditions that the deposition was affected by the marine waters. Such are the deposits made in and on deltas built into the sea and the accumulations of estuaries, lagoons and marine swamps and marshes. The geologic column, as applied to North America shows that most of the Cambrian, Ordovician, Silurian and Devonian systems, more than half of the Mississippian, much of the Pennsylvanian and Permian, considerable parts of the Triassic and Jurassic, much of the Cretaceous, and large parts of the Tertiary were deposited in the sea or in closely adjacent environments.

All the great limestones seem to be of marine origin. Such is also the case for most of the evaporites, as rock salt, anhydrite, gypsum, etc., although the conditions of deposition were not typically marine. In the sea seem also to have been deposited the bedded phosphorites of which those of the Rocky Mountain region are representative. Most of the flints and cherts certainly developed under the conditions of oceanic environments. The great iron formations of the Precambrian are generally interpreted as having been deposited under marine conditions. The oil fields of the world seem related in their origin to marine environments and such wide-spread black and oil shale formations as the Chattanooga, Utica, and Monterey, the generally regarded mother rocks of petroleum, were either deposited in the sea or in environments subject to marine influences.

The sea is the great settling basin for everything washed or blown from the land. It is the final goal of all sediments. It is the place where lived the majority of the organisms known from the geologic column without whose preservation stratigraphy would be a tantalizing and generally barren subject. The accumulation of these vast bodies of sediments in the sea sets in motion physical and chemical processes in the accumulating sediments and the materials upon which they rest. Sequels to such deposition are thought by many geologists to be elevation of parts of the continental areas.

Thus, with so many of the geologic products forming in, or in close connection with the ocean, it is obvious that intimate relationships obtain between oceanography and geology. These relationships will be briefly examined from several points of view with the greater emphasis placed upon those fields of contact with which the writer has familiarity. Different products will be considered from the point of view of single causal factors. This is done for the sake of simplicity, but it should be understood that most, if not all sedimentary materials require the concurrence of several factors in their formation.

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[1] Fourth paper in a symposium, "Major Problems of Modern Oceanographic Research," at the meeting of the American Association for the Advancement of Science, at Pasadena, California, June 17, 1931.

RELATION OF GEOLOGY TO MARINE BIOLOGY

Many marine sedimentary rocks in large or small part are composed of organic matter consisting of the shells, bones, and tests of organisms. These organic materials were formed by animals and plants living in the sea where they were controlled during life and during their evolution by oceanic conditions. The organisms were either invertebrates or vertebrates, the latter interesting and having some geologic importance, the former of extremely great geologic significance. Among other points of view, marine organisms must be studied for determination of the products they are making and the conditions under which the products are made in order that the results of the study may assist in interpreting the rocks and the organisms of the geologic column. Our knowledge of coral reef lithology and faunal distribution over coral reefs and in the adjacent waters was largely derived from the oceanographic work of Darwin, Dana, Murray, Saville-Kent, Vaughan and others, and without this oceanographic work much of the coral reef geology of past geologic periods could not have been interpreted. The varieties of deposits about the reefs —the muds of the lagoons, the sands and gravels in the channels, the coral sands and muds seaward from the reefs, the structureless bodies of the reefs themselves, and the distribution of corals and other organisms on the different parts of a reef—had first to be understood in and about living reefs before the ancient reefs could be interpreted. The work of Howe and Setchell on the contributions of the algae to reef rock and of Walcott on the Precambrian algae has been only partially understood, and more emphasis on this phase of rock-making should be made until it becomes fully appreciated what the algae are doing in modern seas so that their work in ancient seas may be evaluated. The interpretation and appreciation of the algal reefs have lagged in America because of the ignorance or inappreciation of geologists of the great importance of algae in rock building. Since the publication of Pia's great work there is no longer any excuse for such neglect.

The invertebrate life of the sea belongs to the benthos, plankton and nekton. The nekton are not particularly common in the geologic column and do not have a great deal of practical geologic value. The benthos and plankton are of great importance to geology and through them has been constructed in large part the time table of the geologic history of our globe. Each period of earth history is known to have been characterized by a definite assemblage of organisms, and each smaller division was likewise so marked. Most of the fossils in geologic laboratories and those studied by students of geology are invertebrates of marine origin. Stratigraphy would have myriads of problems impossible of solution were it not for the assistance of fossil organisms.

Each of these organisms lived under particular conditions, surviving at a place so long as the conditions permitted and no doubt migrating elsewhere as conditions to which the species was adapted were extended or were moved from one place to another. It needs to be known what are the conditions under which modern marine organisms dwell in order that the environmental conditions under which the ancient organisms lived may be evaluated. It has been assumed that organisms during each division of earth history had quite general distribution in the oceanic waters. Some slight allowances were made for isolation, or provincial development. Oceanographic research has shown that the primary assumption can no longer be made, and reflection should be convincing that it never should have been held. It is known that marine organisms in their distribution are adapted to and controlled by various factors of the environment. Some benthonic organisms are controlled by the character of the bottom, others by depth of water, and others by temperature, light, muddiness, agitation, food supply, low or high salinity, presence of enemies, and other factors. The problems are extremely complex and it seems doubtful if they are completely understood for a single marine environment or for many organisms. The most important factor for the benthos seems to be the character of the substratum or the bottom. Thus, bottoms composed of gray muds have characteristic organisms, black muds have a somewhat different assemblage. Bottoms that are foul are not lacking in organic matter, but this has been developed in overlying or adjacent waters and not at the place. Sand bottoms have a distinct assemblage; similarly bottoms covered with gravels, solid rock bottoms, and those bottoms overgrown with marine vegetation. Some bottoms are colonized by millions of organisms, others, as some sand bottoms and bottoms of black muds, may be veritable marine deserts. Likewise, bottoms subject to changing temperatures may be barren of life, and such is also likely to be the case for those bottoms over which the salinity of the water is subject to wide variations.

Examples of differences in organic association according to environment may be cited as follows. The areas in some estuaries where the twice daily tidal change of water from fresh to salt and the reverse makes an impossible condition for most organisms. The work of Kindle on the organisms in the Bay of Fundy, Walther on Tauben Bank in the Bay of Naples, and Vaughan on the corals of the Cocos Keeling Islands are illuminative on this point, but this work may be said to have just begun.

The abundance of organisms over a bottom is not the only determining factor relating to their occurrence in the geologic column. The problem of the work of scavengers must be given consideration. There are marine bottoms where everything may be expected to be eaten many times. Thus on the coast of Northumberland, England, the bottom to a depth of 24 inches is said by Davidson to make a complete passage through the intestinal organs of lobworms once each 14 months. It follows that before burial to a depth below which the lobworms work, the sediments will make many passages through the intestinal canals. Certain organisms eat everything and Verrill has described bottoms off the coast of New England abundantly populated with benthos, and overlying waters with nekton and plankton, but the dead organic materials covering the bottom are thoroughly chewed to pieces by the scavengers. There are many limestone formations in the geologic column which are shown by their sedimentary structures to have been deposited in waters not subject to agitation of great moment. Many of these show few fossils to the eye, but thin sections prove them to be abundantly filled with fragments. This breaking must be assigned to scavengers. Bottoms with abundant life are certain to have a part of that life devoted to eating the remains of the other parts so that a bottom may be densely populated and yet leave essentially nothing entire for burial in the sediments. Other bottoms with scanty life, but few scavengers, may have abundant remains subject to burial. Some bottoms may support organisms with difficulty because of the frequent influx of muddy sediments, by which at times the bottom assemblages are buried and smothered. Such events render bottoms extremely unfavorable for benthonic organisms, but favor their burial and hence preservation. A muddy condition neither too favorable, nor too unfavorable for benthonic life seems to give greater chances for preservation of organic remains, as the influx of mud may kill the scavengers at the same time as the organisms upon whose dead remains they feed.

Plankton in their adaptation are not so much directly affected by the character of the bottom and the same is true of the nekton, but the latter and, in some cases, also the former are dependent upon some of the benthos for food so that they are indirectly affected.

Thus marine organisms live in colonies adapted to the environment and their abundance on the bottom during life is directly related to those conditions favoring their presence, but their abundance in the rocks of the geologic column is determined by those conditions which permit their preservation after death.

Again the presence of organic remains in sedimentary rocks may indicate little with respect to habits or places of life. In life certain environmental factors determine whether benthonic organisms are present or not; but after death, all organic remains are as inorganic sediments, and movement is dependent upon the competency and capacity of the oceanic waters, and these waters may carry the organic remains to places where the living organisms could not have dwelt. Many examples of shells of existing marine organisms being transported to places impossible for the dwelling of the living animals are known. Thus, on Dog Bay on the coast of Galway, Ireland, the shells of protozoa are carried several miles inland from the sea; the same thing happens to a less degree on the coast of Martinique; on the island of Anticosti crows and gulls carry the testa of the common sea urchin several miles inland and they also carry the shells of the common black mussel, *Mytilus,* equal distances landward from the coast. Currents may bring abundant plankton into the fresh or nearly fresh waters of estuaries and into the lagoons of paralic swamps. The animals perish there, their remains sink to the bottoms and, under conditions of foul or uncongenial bottoms, scavengers are wanting and remains may be preserved in great abundance. In the sound between the Island of Moon and the mainland of Esthonia the bottoms are foul with black mud carrying hydrogen sulphide and living organisms are few. The occasional storms bring in myriads of plankton and the planktonic young and small shells of benthos so that these small shells must be filling many layers. Some day these may be found by some yet to be born geologist and if he base his conclusions merely on the presence of the shells he may assume the bottoms to have teemed with dwarf forms. It is thought that the black shales with abundant planktonic graptolites do not represent the natural environment in which the organisms lived but the abnormal one in which they died.

Thus the marine biologist must give to the geologist not only information relating to the life, products, habits and habitats of the marine organisms but also what happens to their remains after death. He must not only give information relating to the scavengers of the bottom, the places and conditions where organisms are most likely to be buried without removal from the place of life and without destruction of the shell matter, but also to what places they may be transported and what are the evidences of the places of finding being those of the living environment or the places to which the remains were transported. Geologists await this information with expectancy.

When marine biologists have given to geologists the many facts relating to organic distribution, both living and dead matter, many of the data of stratigraphy will no doubt receive different interpretation and many divisions of rocks now interpreted as sequential will be interpreted as arising from lateral variations of the environment and hence contemporaneous. Time relations of some fossil organisms may then be given a somewhat different setting.

Relation of Sediments to Depths of the Ocean

The variety of sediments attaining deposition on oceanic bottoms is conditioned by depth as one factor, this applying to organic as well as inorganic sediments. A few have advocated that deposition in most of the Paleozoic epicontinental seas was uniform from the point of view of the character of the sediments. This view seems so absurd as to be unnecessary of comment. It has also been the view that deposition over an ocean bottom was not subject to serious interruption except by fall of sea-level or building to the surface. Minor interruptions occasioned by limits of supply are not considered. The interruptions caused by fall of sea-level are not debatable providing the fall of the sea brings the bottom above the sea surface, but some doubt exists as to whether it is possible to build the bottom to the surface at many places. Two groups of agents from the point of view of the deposition of the sediments are operative at every place on the ocean bottom and whether or not sediments are deposited depends upon the relations of these two agents to each other. The two groups of agents are complex and on the one hand are concerned with those factors upon which the supply of sediments depends and on the other upon those which are concerned with the disposal of the sediments. Sediments are brought to a given place. If the agents concerned with disposal at that place are equal to the task of removing these sediments no deposition occurs and the sediments are transported to places where the agents of disposal are not equal to those of supply. Such places are in the deeper waters. If the agents of supply exceed the ability of the agents of disposal, the excess is left at the places concerned, a deposit results, and the bottom through this deposit is raised. This brings the bottom nearer to the surface of the water and normally this increases the disposing ability of the waves and currents and deposition at that place is correspondingly decreased. Ultimately the disposing ability of the given place will equal supply and the two groups of agents are in equilibrium. Nothing then attains permanent deposition, and the bottom remains in a constant position with respect to sea-level, the disposing agents can do no more than carry away that which is brought. The position of the bottom is fixed for the conditions and it has attained the position of the profile of equilibrium. When that position has been attained each particle of sediment brought from the sources of supply decreases normally those which remain to be brought with the result that that supply is progressively decreased, but as there is not likely to be decrease in disposing ability the consequence is that the excess in the agents of disposition may be utilized to remove some of the sediments previously deposited and the bottom will ultimately be lowered to some limit determined by the depth at which the disposing agents do not affect the bottom. This is the marine base level of erosion and also the base level of deposition. It is obvious that the level of each profile of equilibrium is determined by the balance between the agents of supply and those of disposal, or putting it in economic terms, by the balance between supply and demand. With large supply relative to disposition factors, the position of the profile of equilibrium becomes high; with small supply relative to the same factors the position of the profile is low. The depth of the base level of erosion is determined by the strength of the disposing agents, the waves and currents, and in the open ocean its depth for a given distance from the shore is probably bounded by somewhat narrow limits.

In epicontinental seas a somewhat different condition exists. The agents of disposal have a limit to their activities, in that the deeps below the base-level of erosion may not exist, or ultimately become filled, so that deposition must take place and thus there is no base-level of deposition and no profile of equilibrium nearer than some level above the water surface and there is little chance of a sinking profile of equilibrium after the central basins have become filled.

Each position of the profile of equilibrium and also the position of the base level of erosion mark breaks in the geologic record and there must be many of these, the duration being either of the nature of diastems or unconformities. In the general run of events most are probably of the order of magnitude of diastems. Deep profiles of equilibrium and the position of the base-level of erosion are most likely to be attained during those times of continental stability when the continents are deeply eroded or even reduced to base-level so that such times should have great stratigraphic breaks developed beneath the level of the sea. Great unconformities on the land shown by overlap of the sea should have continuation developed beneath the surface of the sea.

In this field the geologist needs much assistance. Little attention has been given to breaks in the record which mark times of no deposition or marine erosion. The general tendency has been to assign every break to a land interval, but if the reasoning outlined has validity there should be fully as many breaks that developed beneath the sea. Much work needs to be done to determine the relations of deposition to the bottom. There needs to be determined how extensive are the bottoms receiving deposits, what parts are in equilibrium and stationary, and what parts are being eroded. A little work has been done in this field, but not enough to permit determination of the extents of the stratigraphic breaks that are being developed. The most important piece of work of this character done in America seems to be that done in Chesapeake Bay about the mouth of the Choptank River. Since the location is near the mouth of a river and the areas of erosion and non-deposition are large, 8 per cent. of the bottom being eroded, 66 per cent. being stationary, and only 26 per cent. receiving deposits, it may be concluded that over shallow bottoms of the sea where no large additions of terrigenous sediments are being made there should be extremely extensive areas of non-deposition or erosion.

The variety of sediments that attains deposition is also related to depth. Thus over the deep ocean the bottoms are not congenial to a great variety or number of organisms and between the surface and the bottoms there is vast depth of water through which materials derived from the surface must sink before reaching the bottom. The bottom waters of the deep oceans have come in considerable parts from the polar regions and are thus cold, in which condition they can hold large quantities of gas in solution so that these bottom waters are likely to be adequately provided with oxygen and carbon dioxide. The results are that the bottom waters are oxidizing and at the same time have high solvent action for carbonates. Material coming from the surface is in small particles, probably settles slowly, and has large opportunity to be dissolved and completely oxidized. The results are that carbonates are likely to be taken into solution, even silica is dissolved to a greater or less degree, and the materials deposited are largely hydrous aluminum silicates, aluminum hydroxide, iron hydroxide, fragments of quartz, and other extremely insoluble substances. These materials with some carbonates compose the red clay of the deep abyss. Shallower depths of the deep ocean receive soluble materials from the surface because the height of the column of water through which they sink is not sufficient to take them into solution. Organic oozes may then be deposited over those bottoms where the quantities of other sediments are not so great as to mask the planktonic materials composing the oozes. Still shallower depths receive large quantities of muds brought from the continental areas, these having been brought because the currents at and above those depths were of competency adequate to bring muds and were not of such competency as to bring coarser particles. The presence of these muds masks the planktonic organic sediments and may prevent colonization by the benthos. Thus the organic sediments do not make a serious impress and the deposits are muds of various colors as green, red, gray and blue. These cover extensive areas over various parts of the ocean bottom from the littoral to beyond the edge of the continental shelf. Depth of course is not the only factor in their deposition, but it is an important factor.

Where the terrigenous sediments are not so great and the other conditions are congenial, organic sediments from benthonic animals and plants may dominate in the materials deposited. These are largely carbonates and give rise to limestones, generally interpreted as of deep water origin, but with little evidence suggesting that generalization. Most of the evidence is in harmony with the view that limestone formation by organisms is favored by shallowness of water, in that this is the zone of light, and the other agents that assist in the deposition of lime carbonate seem most likely to be found in shallow water. The coral and algal limestones are quite certainly of shallow water deposition, the former in depths not exceeding 30 to 40 fathoms and the latter limited by the depth to which light may penetrate to enable the algae containing chlorophyll to thrive and utilize the carbon dioxide of the water and in this way precipitate calcium carbonate. How deep this may be done should be carefully determined. Bottoms which are within the zone of light may have immense populations of plants and their presence gives an aspect to the sediments which is not possible if plants are absent. The bottoms of past seas in places became plastered with lime made by algae giving rise to such deposits as those composing the Kona dolomite of the Lake Superior Huronian, some of the limestones of the Precambrian of the northern Rockies of Montana, parts of the Oneota dolomite of the Upper Mississippi Valley, parts of the Arbuckle limestone of Oklahoma, the great limestones of the Triassic of Tirol, and some of the great limestones of the Permian Basin of West Texas.

Holes in the sea bottom of considerable depths below their surroundings have little circulation and are likely to become poor in oxygen. Fine inorganic sediments and organic matter are likely to move to such holes, thus filling them with black muds. The low oxygen content of the filling waters keeps out the scavengers and aerobic bacteria whose presence would eliminate the organic matter and the blackness. Anaerobic bacteria fill these sediments and the presence of some of these lead to reduction of sulphates and the formation of hydrogen sulphide and ultimately the sulphides of iron. The work done by Trask on the sediments about the Channel Islands of the California coast emphasizes the abundance of fine sediments in the holes, whereas the ridges between the holes are characterized by coarser sediments which remain there because the transporting agents on the ridges do not have sufficient competency to carry these coarser sediments to the holes. Goldman has called attention to the black muds filling deep holes in Chesapeake Bay and it seems quite certain that most deep holes of circumscribed area on the shallower parts of the ocean bottom receive fine sediments which ultimately become colored by organic matter.

The great dolomite formations probably bear some relations to depth and also probably to temperature. To the extent that these dolomites are the result of the replacement of calcium carbonate —and most geologists accept the view that the great formational units not affected by magmatic action are of replacement origin—it may be considered established that the original deposition of the calcium carbonate was related to shallow depths. It is generally assumed that the replacement took place in shallow and warm waters and that such is not possible in deep and cold waters. It has been stated that under conditions of atmospheric pressure calcium carbonate is more soluble than magnesium carbonate, but that under pressures of five atmospheres the magnesium carbonate is the more soluble. While observations are not wholly in accord with these generalizations, they may be accepted as more or less approximately correct. The generalization limiting replacement to pressures of less than five atmospheres makes the places of its occurrence on bottoms of shallow depths. If dolomite is ever extensively precipitated as an original sediment it would seem that shallow depths must necessarily obtain, as the double carbonate would have to be deposited where the two carbonates approached equal solubility unless the deposition was affected by organic agencies.

Oceanic research is nearly inarticulate on the dolomite problem and geologists are keenly listening for some words of assistance. The voice of oceanography is also needed to give geologists more definite data on the relations of varieties of oceanic sediments to depth.

RELATION OF SEDIMENTS TO RATES OF DEPOSITION IN THE SEA

The various rates of deposition for different depths are almost altogether unknown. It is assumed that a slow rate of deposition would lead to chemical (diagenetic) changes in the sediments due to the long exposure to the materials in solution and to the work of the organisms upon them. Assumptions have been made that limestone is deposited more slowly than shales or sands, but the assumptions are little more than guesses. The rates of deposition in the deep sea have been thought to be almost negligible. The writer has suggested reasons for believing that the rates may be much larger than generally supposed and that the minimum rate may be of the order of one foot in about 80,000 years, a very slow rate, but considering the immense period of geologic time and the great area of the ocean basins that rate is competent to account for the deposition of greater quantities of sediments in the deep sea than are known upon the lands. It has generally been assumed that the rates of deposition in shallow waters of such sediments as sands must be rapid because they contain ripple marks, cross-lamination, and other evidences of wave and current action. But there are few good reasons for assuming rapid deposition of sands as of general application. As pointed out by Evans, the rates of deposition of some sands may be far slower than the accumulation of any other variety of sediment. A bottom receiving a small supply of sands could not have a considerable thickness accumulated rapidly and before a rapid rate of deposition should be assumed it should be shown that there were large quantities of sands supplied during short periods of time. A bottom at or near the profile of equilibrium and remaining so for a long time might have a few inches or a few feet of sand over the bottom and these might have been deposited and redeposited for thousands of years so that the few inches might represent thousands of feet of any other sediment deposited over bottoms in large quantities and below the profile of equilibrium. Sands deposited on a bottom near the profile of equilibrium with sea-level slowly rising could be deposited no more rapidly than sea-level rose and if this were slow the accumulations might be an inch in a thousand years or ten thousand years and yet these sands could have all the signs of rapid deposition so far as ripple marks and cross-lamination are concerned. Such slow deposition might also be the case for muds or any other type of sediment, organic or inorganic. It is hoped that oceanographic research ultimately will yield the approximate rates of deposition of different kinds of sediments in different depths of water, at different distances from the shore, under other varying conditions, and also give to the geologist criteria for determining whether deposited slowly or rapidly.

Glauconite is a variety of sediment which seems to have its origin conditioned by a slow rate of deposition so that the constituent materials deposited may exist for a sufficiently long time on the bottom to bring about the chemical adjustments resulting in the mineral. Its origin was originally referred to foraminifera, but there is little evidence that these organisms are causally concerned. It seems probable, however, that organisms play some indirect part in the origin as evidence is developing that the glauconite grains represent excremental pellets, and Buchanan and the two Japanese students, Takahashi and Yagi, have described pellets showing the transitions from particles definitely recognized as excremental to those completely glauconitized. In order to permit these adjustments it would seem that slow accumulation of sediments is essential. The bedded phosphorites contain many spherical particles and it has also been suggested that these pellets are of excremental origin which later became phosphatized because of the chemical nature of the sea water and unknown physical factors.

The formation of dolomite may result from conditions of slow deposition as such subjects the original calcium carbonate to leaching and the replacing influence of magnesium carbonate in solution. This is not known, but it may be a lead worth following. It may be that flint and chert are consequences of slow deposition. Under conditions of rapid deposition the silica carried by the streams to the sea would attain wide dissemination throughout other sediments and thus it would not be possible for the colloidal silica to collect in the form of nodules. Under conditions of slow deposition such collection would be possible and thus the nodules could result.

Slow deposition would also make it possible for sediments to become oxidized or reduced. On bottoms containing much plant matter other sediments would be likely to be reduced by the organic materials. Under conditions of rapid deposition the quantity of plant matter might not be sufficient to bring about this result. If the waters contained an adequate supply of oxygen and limited plant and other organic matter, sediments would experience oxidation.

To all the above problems oceanography may some day give the answer and thus render possible the solution of some of the geologists' most perplexing problems.

RELATIONS OF SEDIMENTS TO TEMPERATURES OF OCEANIC WATERS

Oceanographic research has shown that the calcareous sediments are being deposited in greatest magnitude in the warmer waters of the sea, but it does not seem to have been shown what are the quantitative relations of deposition under different conditions of temperature. It is known that some calcareous sediments are being deposited in polar temperate waters, but the quantitative comparison of these with those deposited in warmer waters has not been determined.

It has been suggested that such great black shale formations as the Utica and Normanskill are the deposits of cold waters. Such does not seem likely, but it may be the case. Perhaps such bedded phosphorites as those of the Rocky Mountain region may represent cold conditions, but facts are lacking.

It is known that organisms are adapted to the various temperatures of the oceanic waters and much research has been done along these lines but the application of the data to the fossil organism has permitted various interpretations. The reef corals do not endure a temperature colder than 68 degrees F. at the present time. Do the reef corals of the past have the same temperature significance? This remains to be proven and it is expected that oceanography will give the answer.

The terrigenous sediments of high polar latitudes are largely of mechanical origin and thus have colors related to the colors of the fine particles of the rocks of derivation. Such fine particles are dominantly of light colors and thus it may be expected that the sediments deposited in polar waters would have similar colors. But the colors of many sediments of warm oceanic waters are also light. It may be expected that some day oceanography will produce the data permitting from the colors and other characters of the sediments the determination of the temperatures of the waters in which the sediments were deposited.

Temperature also aids in the precipitation of calcium carbonate as warm temperatures release carbon dioxide and thus may make possible the deposition of some lime. There are no quantitative data on this point.

RELATION OF SEDIMENTS TO WATER AGITATION

It is through agitation of the waters of the ocean that sedimentary materials are transported, bottoms are stirred, and ripple marks and other sedimentary structures formed. These tell of depths, but it is not yet known to what depths agitation extends nor are the natures of the various sedimentary structures formed in the various depths sufficiently understood.

Information is desired with respect to the quantity and quality of suspended matter transported in ocean waters far from land as such data will assist in determining the rates of deposition over the deep sea.

Agitation of the waters also has relationships to the life of the bottom as thus oxygen is brought to lower levels and life otherwise excluded becomes possible. On the other hand, bottoms subject to frequent stirring yield much suspended matter to the overlying waters and thus bring about unfavorable conditions to some organisms, but favorable conditions to some others. Agitation also aids in expelling carbon dioxide and this leads to precipitation of calcium carbonate in waters saturated therewith. The extent to which calcium carbonate is precipitated in this way does not seem to be known.

RELATION OF SEDIMENTS TO THE CHEMISTRY OF THE SEA

This is a large field and one in which not a great deal seems to be known. Sea water seems to be an extremely complex material and the presence and abundance of the various things in solution are related to each other, the temperature, the life in the waters, the presence of matter in suspension, and many other factors. But the precipitation of the things in solution determines some of the things which may be deposited. Under a given pressure calcium carbonate is said to be more soluble than magnesium carbonate. Obviously, if this is true, whether one or the other is deposited or one replaced by the other will depend upon the pressure if that is the only factor considered. When this chemistry is worked out the dolomite problem will be solved. Why were phosphates deposited in large quantities over parts of the ancient seas? Again this is probably a problem of the chemistry of the ocean. The deposition of the fine-grained calcium carbonate of the waters about the islands of the West Indies has concerned geologists for many years and this too is connected with the chemistry of the waters. It is known that sea water has little silica in solution or in the form of colloids. The rivers carry much to the sea but what becomes of it is not known except that it must be precipitated shortly after reaching the sea. It is not known how it is precipitated and why it is that some limestones in a given sequence are full of chert nodules and others have few or none. Obviously, in some way this is connected with the transportation of silica into the ocean. The writer has suggested that the limestones full of chert nodules were deposited near the mouths of rivers flowing from a base-leveled land or a land unable to supply clastic sediments. Oceanographic research will some day yield the deciding facts.

Oolites are forming in the warm and shallow waters of many parts of the ocean. They also form in some salt lakes, as Great Salt Lake of Utah. Many hypotheses have been advanced for their presence, some referring them to evaporation, others to chemical precipitation around nuclei, others appeal to colloids for the formation, and their origin has also been assigned to the action of plants. There are not a great many facts, but there is little doubt that oceanographic research will some day solve the problem and give to geologists the significance of this variety of sediment.

Other chemical products of the sea are glauconite, certain of the zeolites, as analcite and phillipsite, several manganese compounds, and various substances of such minor quantitative importance as the authigenic feldspars. There are many questions relating to all of these which remain unanswered and with respect to some of them essentially nothing is known as to their origin. This is the case for the feldspar crystals which are known to form under some oceanic conditions. There is so much in this field of oceanic chemistry—both the chemistry of the waters and the chemical changes in the deposits (diagenesis)—that is unknown that geologists must be patient if the replies are not forthcoming for a long while.

RELATION OF SEDIMENTS AND SEDIMENTARY STRUCTURES TO THE TOPOGRAPHY OF THE OCEAN BOTTOM

There has been a tendency to assume that the bottoms of the ancient seas were essentially flat, but many parts of the present sea bottom do not exhibit such flatness. It may be assumed that the present sea bottom surfaces are abnormal in this respect, but it would seem more reasonable to assume that interpretations of the character of past sea bottoms are not correct.

The inclinations and irregularities of the surfaces of deposition are important for geology in that the thickness of sediments which may accumulate on a surface is determined by the steepness of inclinations. Slopes that are too steep will not permit the accumulations of sediments, these sliding or gliding to lower levels and frequently becoming deformed in the movement. Data are accumulating to indicate that such gliding with attendant deformation may have been of not infrequent occurrence on the bottoms of ancient seas. Mapping of the irregularities of the shallow water areas of the existing seas coupled with experimental work in the laboratory will show, on the one hand, the inclination of the bottom and the extents of such inclination and, on the other hand, the angles at which various sediments will not remain on a surface. Oceanographers will produce the one line of information; geologists must find the other.

As already noted depressions in the ocean floor become sites of deposition of fine muds many of which are black from organic matter. High places tend to have coarser sediments. Faunas are adapted to each type of sediments as well as to the factors of light, depth, etc. The applications to stratigraphy and correlation are obvious.

RELATION OF OCEANOGRAPHY TO OTHER FIELDS OF GEOLOGY

With respect to other fields of geology the writer can advance his views with less confidence. However, it seems probable that petroleum and natural gas have some connections with oceanographic conditions. The sediments in which the original materials of the oil and gas were deposited seem likely to have been largely of oceanic deposition and oceanic conditions may have been responsible for the organic substances also. Trask has been working on this problem for the past several years and has discovered facts of importance. The great iron formations of the Precambrian are thought to have had their original materials deposited under oceanic conditions, the iron and silica being derived from magmas and precipitated on contact with the sea water. These are applications to economic geology. Similar applications exist for an appreciation of the building materials won from marine deposits, and the utilization of salt, potash and gypsum deposits, and other materials of oceanic origin.

Much has been written relative to a connection between great uplifts and the ocean. Thus one finds such statements as the pressure came from the Atlantic, the settling of the ocean bottom was responsible for the uplift. To what extent any ocean was responsible for any uplift remains to be determined. The movement of sediments from the continents to the sea fills to some extent the ocean basin and raises sea-level, thus bringing about appearance of settling of the continental areas.

The positions of the great basalt flows of the Deccan, Abyssinia, Paraná River Valley, the Columbia River have been interpreted as connected with the sinking of parts of the adjacent ocean bottom with attendant flow of the lava displaced by the settling to the edges of the settling blocks. The outflows of the Deccan and Abyssinia lavas have been correlated with the breaking down of the hypothetical Gondwana land.

Areas of depression in the sea, whether these seas are those upon the continental margins or those within the continents, are places of large accumulation of sediments and that these places of large accumulation later become loci of great deformation and uplift seems established. This was pointed out many years ago by Hall and has become almost axiomatic. Whether the uplift finds a cause in the accumulation, or whether both the uplift and the accumulation are effects of some unknown cause remains to be determined.

The origin of the ocean is a geologic problem not yet answered. There have been various hypotheses; some valid, others fantastic. Perhaps oceanography may some day find the answer.

SUMMARY

There seems hardly any phase of marine sedimentary geology which in some way does not have connections with oceanic conditions and whose solution or extension is not related to the acquirement of information from the ocean. The greater number of fossil organisms known to geologists lived in the ocean. These fossil organisms constitute the chief means of correlation and they are the fundamental materials of paleontology. The greater part of the sedimentary rocks were formed in the sea, and each variety of rock is a response to some combination of oceanic conditions. The ocean in various ways has connections with economic geology and many important mineral deposits were formed in the sea and in some undetermined ways it has relations with the great lines of earth deformation and uplift. The problems are many; the solutions have been few.

SOME PROBLEMS OF OCEANOGRAPHIC CHEMISTRY[1]

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ONE of the factors of paramount importance in the study of the chemistry of sea water, is the selection of suitable analytical procedures. Unfortunately, the literature of the subject contains many articles based on unreliable methods of analysis, the use of reputedly good methods the experimental errors of which are too large to consistently note the minute variations taking place within the sea, and, worst of all, papers are occasionally encountered in which the chemical technique and knowledge displayed would even shame a sophomore. Many of the average analytical procedures do not apply to the study of sea water because of the interference produced by other substances present in the water and thus, in many cases, the methods must be subjected to further analytical refinement. This is particularly true of the analysis of the predominating ions occurring in sea water, as any change due to biological, physical, or chemical factors must necessarily be very small in relation to the large concentrations normally occurring in sea water. Such analyses call for refinements and techniques not usually demanded of the average analytical procedures.

To a certain degree similar statements may also be made for the determinations of the constituents existing in sea water only in very small concentrations; but with these the variations are fortunately relatively large, and the experimental errors of the methods are thus considerably nullified within certain limits.

It has been the practice in the laboratories of the University of Washington to make an exhaustive study of a method before applying it to the analysis of sea water. This is most reliably accomplished by the use of synthetic sea water prepared from carefully purified chemicals. Such a synthetic sea water contains all the major constituents of sea water with the exception of the one being subjected to investigation. Standard solutions of the particular constituent, prepared with all necessary precautions, are then added to the synthetic water in quantities normally existing for a given chlorinity. If a gravimetric process is employed, then spectroscopic examinations are made of the precipitate.

For the major constituents of sea water there are no methods of suitable refinement for field study, except that of the total halides, and such studies must accordingly be made in a well-equipped laboratory. However, for the minor constituents many methods have been developed, within a reasonable degree of accuracy, that can be readily applied in the field and especially aboard ship. Gravimetric methods are generally preferable in most cases because opportunity is offered to finally test the purity of the precipitates weighed. However, volumetric processes are far more convenient and more rapid but interfering ions almost invariably cause difficulty. Thus the Mohr method for halides may be performed with a marked accuracy, as far as the total halides are concerned, but no distinction is possible between the chlorides, bromides or iodides. In this determination the halides are calculated as chlorides and under such circumstances no comparison of this method with gravimetric process is possible unless suitable corrections are made. In like manner the volumetric method for calcium will not agree, theoretically at least, with the gravimetric, unless certain corrections are taken into consideration.

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[1] Second paper in a symposium, "Major Problems of Modern Oceanographic Research," at the meeting of the American Association for the Advancement of Science, at Pasadena, California, June 17, 1931.

Colorimetric methods for the determination of substances occurring only in low concentrations are almost exclusively used. The limits of accuracy and reliability of these methods are too well known for further comment. Too much emphasis, however, can not be placed on the proper control of conditions, especially when the results are to be compared with those of other investigators. Changes in temperature, variations in the amounts of dissolved substances and impure chemically-pure chemicals may often lead to erroneous conclusions, if not properly considered. In many of the colorimetric methods applied to sea water variations in the dissolved salts have a pronounced effect. Wattenberg has nullified such errors in his modified method for ammonia, Thompson and Bonnar used a similar procedure in the development of the determination of the buffer capacity of sea water and at the present time Dr. Carter, of the Pacific Biological Station, is perfecting the procedure for the estimation of nitrates.

The constancy of composition of sea water was postulated many years ago and has been sufficiently demonstrated for the predominating ions to a certain limit. Thus sea water varies only as to the degree of dilution and therefore the physical properties vary as the dilution, temperature, and pressure remain constant. One of us, in a recent paper, made the following statement:

> While the constancy of composition of some of the major constituents of sea water has been demonstrated within certain limits, it must be borne in mind that the sea is a system of tremendous complexity. Vast numbers of actions and reactions of a physical, chemical and biological nature are continually taking place. Substances in suspension and in solution are continually being poured into the sea. All the myriad forms of plant and animal life bring about a complicated series of changes. The formation and melting of sea ice, atmospheric effects, volcanic activity, and slow geologic processes, all exert an influence upon the composition of the waters of the seas. In spite of the vastness and complexity of innumerable factors, a point of balance or equilibrium persists. The resultant of any effect when compared with the entire mass of water may be very small, hardly detectable for the predominating ions, but readily measurable in many instances for those occurring only in very low concentrations. Thus an increase or decrease of 0.1 milligrams per liter of sulfate ion in a water containing 2,500 milligrams per liter of the same ion could hardly be measured, but an increase or decrease of the same amount of the phosphate or ammonium ions in sea water would readily be measured and would undoubtedly be described as a most decided change. In other words, the predominating ions in sea water appear to be present in quantities that are definitely proportional to one another, but those existing in very small concentrations tend to vary materially according to conditions.

In the light of the above statements these substances of small concentrations present a most fascinating and fruitful field for study and one that will throw much light upon the various processes taking place in the sea. Up to the present time, variations in phosphates, nitrates and silicates have occupied the attention of many investigators, and much useful information has resulted. However, the presence and variation of a long list of other substances occurring only in minute traces have been practically ignored, due solely to lack of reliable and consistent methods of analysis. In some of the European waters the limiting factor for the mechanism of certain biological processes has been shown to be due to phosphates and nitrates, but Atkins concludes that silicates are not a limiting factor for these waters. The general experience on the Pacific Coast of North America has been that none of these substances are limiting factors, except in certain estuaries, because of the marked evidences of upwelling from the ocean depths. The rôle played by iodine, fluorine, lithium, strontium, manganese, iron, copper, etc., and the extent to which they actually occur in sea water is unknown. In many instances the situation is complicated by the presence of organic matter. This organic material undoubtedly contains the secondary alcohol group and under such circumstances many of the metallic ions react with it to form complexes and therefore direct analysis is defied.

In many of the studies of sea water very little distinction has been made concerning the nature of the various waters, and the universal custom has been to designate the differences almost solely on differences in salinity. While true ocean water is of constant composition, varying only as to the dilution, accurate studies of ionic ratios show that there may be very slight differences between the waters of the several oceans. However, it has been shown in the laboratories of the University of Washington that with more diluted waters, such as found in the Baltic Sea, at the mouths of rivers and in certain stagnant areas, the ionic ratios may show considerable variation. The diluting waters will invariably cause an increase in the ionic ratios unless there is considerable adsorption by the suspended particles in the fresh water as they come in contact with the sea water or marked evidence of bacterial action in the brackish water. Thorough detail studies of the physical and chemical phenomena of brackish waters, such as found at the mouths of rivers which deposit waters unpolluted by industrial wastes, will give most important information. Such data would be invaluable for comparison with conditions where the diluting water is highly polluted, and point to possible remedies and regulations that must be made in regions where the seashore is densely populated over a wide area and where there is marked industrial activity. The detail chemistry of the waters of lagoons, of oyster beds, salt marshes, long narrow estuaries where there is little complete flushing of water, etc., all offer most interesting problems, but the average oceanographical chemist, working by himself, is appalled by the vast amount of very accurate data that must be accumulated before he is justified in drawing conclusions.

Whether the great biological activity along the coast lines is due to physical, chemical or biological conditions, or a combination of all three factors, can not be stated, but the chemist can certainly supply data that would aid in the solution of this most complex problem.

The study of the presence of dissolved or chemically combined gases is a field that has attracted many investigators. Due to the simplicity, accuracy and ease of duplication of results, Winkler's method for the determination of dissolved oxygen has resulted in the collection of much useful data from which far reaching conclusions have been drawn. However, the rather unusual and interesting results in the study of the distribution of dissolved oxygen obtained on the last cruise of the *Carnegie*, indicate that there is a great deal that is yet unknown. In fact it might be better to say that this study of the *Carnegie* has initiated a series of perplexing problems as to the distribution and circulation of dissolved oxygen in the oceans proper.

Unfortunately, the study of dissolved nitrogen has been seriously neglected, largely due to the difficulty of the methods of the determination, particularly on board ship. To obtain a knowledge of the nitrogen cycle in sea water, many determinations of dissolved nitrogen are imperative. The possibility of nitrogen fixing bacteria in the sea has been hinted by several authorities, and probably one of the best methods of the demonstration of the existence of such bacteria would be through studies of the distribution of dissolved nitrogen.

Like dissolved oxygen, the presence of free carbon dioxide, bicarbonate, and carbonate ions has received considerable attention, but much of the most outstanding work on this subject has come from results based on purely laboratory conditions. The relationship between pH, dissolved oxygen, carbon dioxide and total alkalinity has been shown to hold rather exactly for closed systems in which all conditions may be controlled, but when these data are applied to the sea itself, situations are ofttimes encountered which do not harmonize in any way with those that would be predicted from laboratory data. Whether one is warranted to make certain calculations dealing with the different phases of carbon dioxide equilibria on a purely physical chemical basis seems to be open to question, but perhaps all conditions have not yet been taken into account.

THE METAMORPHOSIS OF THE HORSE DOCTOR

By T. SWANN HARDING

MT. RAINIER, MARYLAND

IF a man gets sick in this country to-day there is no sure way for him to procure the services of a conscientious and competent medical doctor. It is, therefore, a curious fact that if a man had a sick horse to-day, he would not be compelled to wonder where he might obtain the services of a good veterinarian. He could wire the Bureau of Animal Industry at Washington and find out the approved or the accredited veterinarians in his vicinity and be sure when he selected one of them that he had a well-trained and competent man in charge of his horse. It is furthermore a fact that, so well organized has veterinary medicine become in recent years, there actually exist less and less diseases for horses, cows, hogs and other lower animals to contract. For veterinary medicine has gone in the business of producing animal health *en masse;* it has very largely substituted wholesale for retail methods. Without sacrificing anything of real value in the individualism we all cherish so much and understand so little, it has stimulated hundreds of scientists of various sorts to work together for the good of animal health, and its accomplishments are such as to bring pause to human medicine.

For, come to think of it, what ever became of the old-fashioned veterinarian? The old fellow had a gig, a knife, a needle, a ball of twine and a few other instruments he was continually getting mixed up with the carpenter's tools. He rode round the countryside cutting hogs, opening abscesses, or visiting individual horses, hogs and cows in the manner medical doctors visit to this day. How many of him did we have then and how many now? How many veterinary schools were there then, and what sort of education did they provide? How about now? How many veterinarians does the Bureau of Animal Industry now employ and what has this bureau accomplished? What part has it had in enabling the veterinarian to combat animal disease in wholesale fashion? The average human doctor, even to-day, regards the veterinarian as an inferior sort of animal somewhat lower than a dentist but perhaps on the mental level of an osteopath or a chiropodist. What reason has he for this attitude? Is the human medical profession even as well organized as veterinary medicine to-day? Hasn't veterinary research actually made important contributions to human medicine? Isn't the veterinarian worthy of more respect now? In short, hasn't he shed his horse-doctor integument to become a serious scientist whose work the human physician might rather emulate than deprecate? Let us see.

Many people are under the impression that the horse doctor is as extinct as the horse. Not so at all. Neither animal is extinct. Raymond A. Pearson[1] assures us that the veterinarian is not passing. He also reminds us that we owe the existence of the Panama Canal to veterinary medicine, because Smith and Kilborne's solution of the Texas tick-fever problem supplied the technique for the control of yellow fever —and there you are.

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[1] *Journal of the American Veterinary Medical Association,* October, 1927.

David S. White, dean of the college of veterinary medicine, at Ohio State University, remarks,[3] however, that while 85 per cent. of our medical graduates to-day have baccalaureate degrees, only 2 per cent. of our veterinarians possess them. Furthermore, there are twice as many students in our medical schools as there are practicing veterinarians in the entire United States. However, low entrance requirements and quick courses for veterinarians are passing.

In 1890 Dean White went to Europe for three years' study and he returned to find a former vacant lot occupied by a school of veterinary medicine with 400 students attending, and which had already sent forth one entire graduating class! To-day, we have but a dozen recognized schools of veterinary medicine in the country, with a total of some 700 students, and not more than a few over 100 students at the largest of them. Germany, which is the size of Texas and has about one third our animal wealth and one half our population, has five well-equipped schools of veterinary medicine; France, with one third our population and one fourth our animals, has three schools; and Great Britain, with 40,000,000 population and one fourth our livestock, has four. The total livestock of all these countries combined amounts to one half our horses, two thirds our cattle, and three fifths our swine or sheep, yet these countries have as many schools of veterinary medicine as we do and double the number of practicing veterinarians. This indicates that veterinary medicine has been a little too much neglected in America in view of rational, scientific requirements.

An editorial in *The Prairie Farmer*, October 12, 1929, says:

> It is reported from the Kansas Agricultural College that the enrolment in the veterinary courses this year is higher than for many years back. This is encouraging, for a real and serious shortage of competent veterinarians is imminent in the near future unless more young men of the right kind do decide to fit themselves for the practice of veterinary medicine. Most people do not realize the importance of the veterinarian in maintaining the health and well-being of our farm animals, and still less do they realize how much the health of the human race depends on the health of the beasts. Rabies, anthrax, and glanders, to say nothing of tuberculosis, are all terrible diseases that are easily communicated to man from the lower animals. While it is a fact that the spread of knowledge of sanitation and animal hygiene among the farmers will do much to head off animal disease, nevertheless, it is still true that the brunt of the battle must be borne by the men who are trained specifically for the task—in other words, the veterinarians. The lack of trained men opens the way for the quack and the vender of nostrums. As the country grows older and the number of animals increases, the problem of disease and parasite control becomes more serious—that is a plain fact that cannot be controverted. Twenty-five years from now we will consider ourselves fortunate if we have a sufficient force of veterinarians adequately trained for the task that will be theirs.

According to an article in the August 25, 1927, *Hoard's Dairyman* on "The Veterinary Situation," by D. S. Burch, veterinary medicine arose in France in 1762 with the object of training men to save war horses. The first college was established in the United States in New York in 1857. To-day all our private veterinary colleges are closed for lack of students, and only full-time, four-year-course state colleges remain. Three thousand students enrolled in 1916; 582 in 1926; the 132 graduates in 1926 would not fill Bureau of Animal Industry vacancies alone, as it employs 1,350 veterinarians with an annual 10 per cent. turnover. When hog cholera ran amuck in September, 1926, serum could not be made fast enough and one and five tenths million hogs died unnecessarily because serum could not be prepared in less than two months. The veterinary shortage is even more severe than the serum shortage as it takes four years to make one veterinarian! Yet the field for well-trained veterinarians has broadened greatly and includes disease control, city milk and meat inspection, state and county veterinarians, the manufacture of biologicals, promotion of stock raising, army work, teaching, equine work on 17 million horses, tuberculosis testing, fur farming with valuable breeding stock, and the poultry industry. There are now only 10,000 veterinarians in the United States, or scarcely one for each 18,000 domestic animals, not counting dogs, cats, fur bearers, or poultry, and many of the number are perhaps near retirement or are already partially inactivated.

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[3] *Journal of the American Veterinary Medical Association*, February, 1929.

Each year the report of the chief of the Bureau of Animal Industry calls attention to this situation and the bureau has been most active in fostering veterinary education. In 1927 the number of colleges whose graduates were eligible to compete in United States Civil Service examinations was 12. The freshmen registered were 193 as against 165 the previous year. A marked shortage of veterinarians for over 30 years was deplored. In 1928 the number of accredited veterinary colleges remained 12, but 242 freshmen were enrolled, there were 136 graduates, and "a growing recognition of the veterinary profession as a promising career for young men" was presaged.

The fact should be emphasized that the United States Government, through the Bureau of Animal Industry, without being autocratic, and without any unpleasantness, has taken stock of the situation, and has aided materially in weeding out low-grade colleges. The entrance standards and educational requirements of colleges have been raised, and the country now has well-trained and well-equipped veterinarians. Finally, the Bureau of Animal Industry has so successfully advertised the shortage of veterinarians that increased enrolments are now observed and we shall soon have as many highly trained, accredited veterinarians as we need—considering the manner in which the combat against animal disease is organized. It is, therefore, quite possible for a government agency skilfully, quickly and efficiently to renovate a profession in all its branches, and thus to render the public a tremendous service. If some such overhauling could be carried out in the profession of human medicine, most of the pressing problems which so agitate and beset us in this respect would automatically disappear.

For, in spite of depleted numbers, our veterinarians care for a tremendous animal population in what must be a very efficient manner. The domestic animal population was one and one third times our human population, or 183 million, in 1922, according to Dr. John R. Mohler.[3] According to the 1920 census our horse and mule population was 27,283,413, and 17 to 19 million animals were regularly needed for draft work in crop production, while 2 to 3 million more were required in nonagricultural work. According to Pearson,[4] the value of livestock on American farms was 3 billion dollars in 1900 and 5 billion in 1926, the latter being a low figure due to temporary conditions. There had been no decrease in the number of horses and there were more horses on our farms in 1910 than in 1900, and in 1920 than in 1910. Mules had increased in number rapidly. Besides that we slaughter some 115 million animals annually which must be examined for disease, and cows, beef cattle, sheep, swine and small animal pets abound. Pearson said there were 21,532,000 horses and mules on American farms in

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[3] *Journal of the American Veterinary Medical Association*, 62, 592.

[4] *Journal of the American Veterinary Medical Association*, July, 1927.

1900 and 22,312,000 in 1925.[6] Finally, the U. S. Department of Agriculture Circular 241, which contains a livestock census in tabular form from 1850 to 1929, notes a steady increase in our cattle, sheep and swine population.

The disease problem confronting the veterinarian bifurcates into two distinct parts: (1) The fight against animal diseases *per se,* and (2) the eradication of animal diseases which can readily attack human beings as well. Hence veterinary medicine is closely related to human medicine. The toll from animal disease may total $200,000,000 annually from stock loss alone. The country must be and is efficiently protected from invasion by foreign animal diseases, such as contagious pleuropneumonia, rinderpest, surra, Malta fever and the foot-and-mouth disease. When dourine (an equine venereal disease) menaced the horses of ranches in the Dakotas, Montana, Wyoming, New Mexico and Arizona, and control measures proved unavailing, a complement-fixation test for its detection was developed in 1912 and the disease was thereafter rapidly eliminated. Hog cholera has scourged American swine for ninety years, but a serum, also developed in the Bureau of Animal Industry, in 1905, gives temporary immunization and that, plus virus, gives permanent immunization which, together with quarantine and sanitation, will cut the losses almost to nil. Cooperative tick eradication began in 1905 and must proceed to the last tick, which will thus banish Texas fever. Investigation continues on bovine infectious abortion and as soon as the bureau's general staff has its method ready, the disease will disappear. More rapid tests for the detection of animal tuberculosis have been developed and infected animals are rapidly being eliminated from herds.

A calamity like the foot-and-mouth disease demands the wholesale destruction of herds of valuable cattle. Congress grants an indemnity for herds destroyed, but this is not legally compulsory; it is a mere gratuity, the destruction of the sick animals being legally regarded as the abolition of a nuisance. Often 100 per cent. eradication of contagious animal diseases has been accomplished. Glanders is now a curiosity; dourine is nearly gone; Texas fever is greatly diminished; scabies is controlled, and lip and mouth ulcers no longer menace sheep; "hollow-horn" and "wolf in the tail" vanished some time ago.

The fundamental research performed by the Bureau of Animal Industry in 1888–1893 which demonstrated that a microorganism found in the blood of cattle affected with Texas fever is the actual cause of the disease, and that the cattle tick was the intermediary host, was the first demonstration that a microbial disease could be transmitted exclusively through the agency of an intermediary host or carrier. This discovery ranks with the foremost achievements of medical science, for it led to the knowledge that yellow fever, malaria, typhus fever, African sleeping sickness, Rocky Mountain fever, nagana and other such infections were carried by an intermediate host. The development of the complement-fixation test used in dourine led to further discoveries in this line in the investigation of botulinus toxin and cerebrospinal meningitis in horses. It also led to the

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[6] The following table given in one of the most recent of the Department of Agriculture publications indicates, however, that very recent estimates show a decline in the horse and mule population.

Horses and mules	1920	1929
On farms	25,323,000	19,506,000
In cities	2,084,000	1,450,000
Totals	27,407,000	20,950,000

This is a decrease of 6,457,000, or 23 per cent.

development of an immunizing agent against hemorrhagic septicemia, or sleeping fever, of cattle, a biological product now prepared commercially, which has proved potency and has saved livestock men enormous sums of money. The Bureau's discovery of a new species of hookworm prevalent in the Southern States led eventually to the establishment of the International Health Board of the Rockefeller Foundation, and the Bureau's subsequent introduction of carbon tetrachloride as a remedy for hookworm disease has resulted in the treatment therewith of 15 million cases throughout the world. This, too, we owe to governmentally financed veterinary medicine. Research on the intestinal roundworm of swine led to a new system of hog raising based on protection from roundworm infestation and a saving of a million a year in the Corn Belt alone.

Each annual report of the Chief of the Bureau of Animal Industry notes the vigilant and effective pursuit of this scientific work. In 1927, for instance, 347 counties were observed to be free from bovine tuberculosis; a survey of animal parasites was undertaken; there was a record production of hog-cholera serum which checked serious outbreaks of that disease; many more counties were announced free of Texas ticks; research progressed as usual. In 1928, the report observed that 11,300,000 cattle were tuberculin tested; further counties were released in the tick eradication work; supervision over licensed establishments producing animal biological remedies was successfully continued; the country was protected against a dangerous outbreak of foot-and-mouth disease; progress was reported in work on infectious abortion, which exacts an annual toll of $50,000,000; animal parasite investigations were continued and the problem of anaplasmosis was attacked.

As we have already seen, and as J. Howard Beard reminds us, "The Veterinarian Contributes to Public Health."[6] For man also is susceptible to tuberculosis, anthrax, Malta fever, rabies, glanders, pyogenic infections, foot-and-mouth disease, diphtheria and trembles. Anthrax is as old as history. Moses described "a boil breaking forth with blains upon man and beast." Homer, Seneca and Virgil mention the disease. In 1849 the human and animal types thereof were found to be identical; we owe much to the later work of Pollender, Koch and Pasteur. The first case reported in America was in Philadelphia in 1834; Louisiana suffered anthrax epidemics in 1835 and 1851 and cases had occurred in every state by 1900. There were eighteen cases with nine fatalities in New York City in 1919–1920. Men handle animal products and easily become spore infected. Trichina, one of the roundworms of rats and hogs, causes gastro-intestinal trouble in man with fever and muscular pains.

Naturally, therefore, veterinary research is valuable in combatting human diseases. The study of splenic fever and the cattle-tick-born fever helped us understand Rocky Mountain spotted fever, relapsing and South African tick fever in man. The investigation of surra in horses and nagana in cattle offered suggestions for the treatment of trypanosomiasis in man. Pasteur's immunization of chickens against cholera and of cattle and sheep against anthrax was a forerunner of our human typhoid, cholera and plague inoculations. The study of malnutrition in livestock definitely assisted in the study of human pellagra, scurvy, rickets, beriberi and the other metabolic diseases. Tumors in animals have been studied to the advantage of cancer research. Treating the young animal helps the pediatrician while the obstetrician learns from abnormal parturition and *post partum* illness in animals. In his "Animal Reservoirs of Human Diseases,"[7] Theobald Smith went very thoroughly into this subject and mentioned the following diseases as transmissible from animal to man: glanders, bubonic and pneumonic plague, Malta or undulant fever, tularemia, rat-bite fever, infectious jaundice or Weil's disease, anthrax, rabies, paratyphoid diseases, tuberculosis, Rocky Mountain spotted fever, septic sore throat, besides other pathological conditions caused by higher animal parasites.

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[6] *Nation's Health*, June, 1921.

In all this work the Bureau of Animal Industry may be regarded as a sort of general staff headquarters. Its activities are not autocratic, nor do they deny the opportunity for individual service among private practitioners of veterinary medicine. Through its ability to establish quarantine for the control of animal diseases the bureau has, of course, some leverage in cases where state cooperation might be dilatory, but local cooperation is usually excellent, though the bureau's leadership in planning and conducting disease-control work from a national standpoint can not be denied. Policies regarding livestock-sanitary problems are formulated for the most part at conferences of the United States Livestock Sanitary Association in the affairs of which bureau officials have long been active, and the decisions of the organization are quite uniformly in accord with bureau recommendations.

The Bureau of Animal Industry in Washington is so organized that the well-correlated efforts of every type of research scientist indicated are coordinated for the one end of animal disease eradication. Here is a case where highly organized research, directed at a very definite end, accomplishes theoretical results and practical applications of fundamental importance. Furthermore, the bureau maintains a list of accredited and another of approved veterinarians. These men are private practitioners who, by examination or otherwise, have demonstrated their ability to perform certain classes of work to the satisfaction of bureau standards. An accredited veterinarian is a higher grade man than an approved veterinarian, and any citizen, by writing to the bureau, may learn the names of the accredited and approved veterinarians in his locality.

It is, of course, still true that some old veterinarians who are little better than charlatans remain in practice, but the type is rapidly dying out and is being replaced with highly qualified men. It is also true that a horse might yet manage to die unnecessarily of some ailment which was not too contagious nor infectious, provided his owner could not afford to pay an accredited or an approved veterinarian. But the real point to be considered is that while human beings are still exposed to really preventable diseases like malaria, tetanus and diphtheria, and while human medical research is sporadic, ill-coordinated and frequently involves shameless duplication of effort, so thoroughly has veterinary medicine been organized that the animal is well protected against any pathological condition preventive medicine can eradicate.

Of course, a disease like foot-and-mouth, which is widely prevalent elsewhere in the world, must occasionally get into this country by chance. That has happened nine times in the past 60 years, and it happened in California in January, 1929. That outbreak was completely eradicated two months after its discovery. Why? Because the Bureau of Animal Industry has an established method of combatting such outbreaks and maintains a trained and experienced force of foot-and-mouth disease fighters that is not equalled in any other country. The government ably finances this work and no time is lost when an outbreak occurs.[8]

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[7] *Bulletin of the New York Academy of Medicine*, 1928, Vol. iv, 476–496.

Consider the 1929 outbreak. It originated in Los Angeles County. On October 6, 1928, the S. S. *City of Los Angeles* left San Pedro for a South and Central American cruise. On November 2 she took on board approximately 18,000 pounds of fresh meat at Buenos Aires. She still had some of this on hand when she reached Wilmington, California, on December 8, 1928, and on December 20 transferred some of it to the S. S. *Caliwaii*. This ship sailed for Honolulu on December 22 and the *Los Angeles* followed her on December 29. Both ships used up all their South American meat before returning to port January 12 and 18, 1929, but the trimmings from this meat were transferred to garbage cans along with other garbage and discharged from the ship; the garbage, infected with foot-and-mouth disease from the Argentinian meat, was steamed, collected for the San Pedro Commercial Company and later sold to the owners of two large hog ranches—Mr. Frank B. Haas and Russell and Knight. Foot-and-mouth disease appeared on the Haas ranch only.

Mr. Haas first noticed lame hogs on January 10. This might be attributed to broken crockery, but on January 11 there were other lame hogs, and on Sunday, January 13, still more lame hogs were found in an adjoining pen. Mr. Haas now tried to get in touch with the county department of livestock inspection by phone, but failed; he left word for Dr. Conti of this inspection service to visit his ranch on the fourteenth. Dr. Conti examined the animals, made confirmatory inoculations of other animals, quarantined the premises, and notified Dr. Snyder, the Bureau of Animal Industry cooperative inspector in the district. On January 16, Dr. Suyder wired the bureau at Washington that he believed the hogs had foot-and-mouth disease; on the seventeenth, inoculation tests proved positive; federal quarantine was established on the nineteenth, and all infected and exposed animals were slaughtered and buried at once.

For a while thereafter no new cases appeared. On January 30, however, a nearby herd of 51 dairy cattle was found to be infected, was appraised, slaughtered and buried. On February 2 another nearby dairy herd of 75 developed symptoms and was disposed of that night. A fourth herd, composed of 33 dairy cattle, was discovered infected at noon, February 6, and was appraised, slaughtered and buried that afternoon. The fifth and last herd was found infected on February 16; it was composed of 67 animals and was buried without military honors the same day. No further signs of the disease appeared and quarantine was lifted March 18. The quarantined premises were each immediately surrounded with high fences of chicken wire, which barriers excluded dogs, cats and poultry, and also gave assurance that hay, manure and other possible carriers of the disease were not removed from the premises.

The method was drastic and sanguinary, but it was effective. The country was protected from one of the most dangerous cattle diseases in existence. The personnel in charge is thoroughly trained, and individuals moved to the focal point as directed from Washington, and performed their duties in a business-like manner. Walking in, killing a man's valuable cattle, paying him the appraised price the government grants, digging a trench with a machine, casting in the bodies, ripping up the hides and covering the entire mess of meat with lime both invades his domain and smacks him squarely in the face with a large gob of state socialism. But it represents organized effort acting effectively in a social emergency and it serves its purpose. In the case of smallpox, however, it is difficult for the authorities to enforce vaccination upon individuals who resent such interference with their "personal liberties." In the case of certain other diseases among humans, eradication would be fairly easy if physicians but conscientiously did their part. Finally, the fundamental tenet of economically organized medicine in America to-day is absolutely fanatical individualism, and the slightest tendency towards soundly organized efforts to control disease on a national basis is denounced by the journals of the medical guild as "pauperizing" the public or as state socialism.

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[8] J. R. Mohler, *Journal of the American Veterinary Medical Association*, September, 1929.

It is, of course, very much easier to eradicate animal diseases than to wipe out human ailments because, if you can't do anything else, you can kill a few hundred patients. This does not materially affect the major thesis of the present paper, *i.e.*, that veterinary medicine has been so efficiently organized to combat animal diseases that the result has been the complete eradication of some diseases and very serious inroads upon the disastrous effects of others; furthermore, that within a very short period of time, the status of the veterinary profession has been raised and effective means have been devised to use without delay the latest findings of an organized body of scientists of various sorts, engaged in fundamental research, in a practical way, to fight diseases among animals.

In short, a sick or indisposed animal is regarded as an acute social problem about which the community, through "socialistic" (if you please) governmental agencies is prepared to take action. But a sick man is not at all sure of such certain expert care—at least not so long as experts insistently inform us that preventable deaths cost billions of dollars annually in America to-day.[9]

[9] This article was personally corrected and endorsed by Dr. John R. Mohler, chief of the United States Bureau of Animal Industry in the Department of Agriculture, in so far as it is concerned with the activities of that bureau.

SCIENCE SERVICE RADIO TALKS

PRESENTED OVER THE COLUMBIA BROADCASTING SYSTEM

THE RÔLE OF CELLULOSE IN INDUSTRY

By Dr. HENRY K. BENSON

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THE instinct to keep a diary is well-nigh universal, even in ancient times. The materials used for writing at first were those that required but little mechanical fashioning to fit them for that purpose. The love letters and patriotic orations of ancient times were engraved on flat stones or were impressed in clay which was afterwards dried or hardened by sun or fire as in the Babylonian tablets. Thin boards of wood covered with wax and plates of ivory or metal have been used. The skins and intestines of animals have also been made fit for writing upon; and there still exists in the Sorbonne in Paris a manuscript certified by an ancient librarian to be written upon human skin as well as an elegant copy of the Bible which the Abbe Rive believed to be on the skin of a woman. Little wonder that it should have been a beautiful edition.

When the Egyptian papyrus was introduced, all these things fell into disuse except the parchment made from the skins of sheep and young goats, which is still preferred for certain purposes such as college diplomas and other rarely used documents. Quite appropriately, the parchment made from the skins of old goats is used for drums and tambourines.

The nearest resemblance to modern paper was that made in Egypt from the papyrus plant. This plant has a soft cellular flower stem ten to twenty feet high, of a triangular shape and made up of thin coats of plant tissue. These thin coats were separated by means of pointed mussel shells, spread on a table sprinkled with Nile water in such form as the sheets required and washed over with the same. On the first layer of these slips, a second was placed crosswise so as to form a sheet of convenient thickness, which after being pressed and dried in the sun, was polished by means of a shell. The paper metropolis of Egypt was Alexandria, which supplied Europe and Asia for several centuries and acquired immense riches thereby. So profitable was the business that one individual boasted that the revenue from the paper in his possession would maintain a large army.

We are now making paper from fibrous material floating or suspended in water. For the discovery of this art some 1,800 years ago, we are indebted to the Chinese. They used the inner bark of the bamboo and mulberry tree as well as hempen rags. The pulp obtained was made into paper on a frame of fine reeds, pressed under large stones and dried by fastening the sheets on the walls of a room. The Chinese also made paper from cotton and linen rags and from rice straw. Their art was evidently transmitted to the Hindoos and the Arabians, who carried it into Spain, where, after the expulsion of the Moors, it spread into the other countries in Europe. In the latter part of the fourteenth century, linen paper was made in England, and in 1712 Peter the Great of Russia was so much pleased with what he saw in a paper mill at Dresden that he engaged paper makers whom he sent to Moscow to establish a paper mill at his own expense.

The manufacture of paper in the American colonies was early established, the first plant being that of William Rittinghuysen near Philadelphia, in 1690. Apprentices from this mill became the pioneers of the American paper industry. The raw material in this country was rags, and purchasing agents in those days had the skill and culture of modern sales agents. In the *Boston News Letter* of 1769, it was announced that "the bellcart will go thru Boston before the end of next month to collect rags for the paper mill at Milton," and to aid the public zeal these lines were appended:

Rags are as beauties, which concealed lie,
But when in paper how it charms the eye;
Pray save your rags, new beauties to discover
For paper, truly, everyone's a lover;
By the pen and press such knowledge is displayed,
As wouldn't exist if paper were not made.
Wisdom of things, mysterious, divine,
Illustriously doth on paper shine.

And again we listen to a masterly appeal in New York:

> Save your rags! This exclamation is particularly addressed to the ladies both young, old, and middle-aged, throughout the northern part of this state by the subscribers who have created a paper mill in the town of Moreau, near Fort Edward—nor is it thought that this appeal to our fair countrywomen will prove unavailing when they reflect that without their assistance they can not be supplied with the useful article of paper. If the necessary stock is denied paper mills, young maids must languish in vain for tender epistles from their respective swains; bachelors may be reduced to the necessity of a personal attendance upon the fair, when a written communication would be an excellent substitute. For clean cotton and linen rags, of every color and description, matrons can be furnished with Bibles, spectacles and snuff; mothers with grammars, spelling books and primers for their children; and young misses may be supplied with bonnets, ribbons and earrings, for the decoration of their persons (by means of which they may obtain husbands) or by sending them to the said mill they may receive the cash.

I have drawn on the history of paper making to show you the slow transition of the centuries from the papyrus of the Egyptians to the fibers obtained from the cast-off clothing of the population of the whole world. In a book dealing with the progress of paper making, published in 1876, the author says that although experiments under way at that time were so successful as to lead many to hope for an economical mode of converting the forests into paper to supply the all-devouring maw of the press, yet "it is still thought that we shall never find anything to answer the purpose so well as linen and cotton rags."

To-day this forecast no longer applies. We have turned from rags to the ever-renewing and perpetual forest mantle of the earth for our supply of fibers, and through our knowledge of chemistry we have learned to utilize the giants of the forest for the printed pages of our culture. The tree has taken on an unwonted reverence. In kindred sciences we have learned its life history. We know that the magic of sunlight transforms the moisture of the soil and the carbon dioxide of the air into cellular structures akin to starches and sugars, and to protect them against the storms of centuries, nature has insulated these fibers by thickening them and coating them with a highly resistant material to which we give the name of lignin.

The problem that confronted the paper industry fifty years ago was to find a solvent for this lignin coating. The answer came in the processes that utilized caustic soda and sulfurous acid to dissolve the lignin and thus release the fibers of cellulose and so to interweave them in thin layers as to constitute the paper sheets which we now use so extensively and upon which we are so dependent for the spread of knowledge and extension of culture.

The future requirements of pulp and paper are difficult to forecast. Shoes, socks and shirts are sometimes made from paper. We try to drink coffee or cocoa from paraffined cups. The sanitarian has banished the old towel and makes us blot our faces instead of wiping them. The fruit industry wraps its products in tissue, the poultry industry packs its eggs in cardboard trays, the dairy industry seals its butter in paper cartons, the cement industry delivers cement in paper bags; even explosive materials used in blasting are shipped in paper bags, ready for the farmer to mix and blast out a stump. The interiors of houses are often largely constructed of wood pulp; it is only necessary to apply some waterproof coatings which we have in order to use wood pulp for the exteriors as well, and as the per capita consumption of lumber diminishes that of pulp and paper increases. It is not too much to expect that soon we shall sail the high seas in ships of paper, fly through the air upon wings of paper, and dwell in houses of paper.

Spectacular as this forecast of the future uses of cellulose in pulp and paper may be, yet more striking are the uses to which it has been put in chemical derivatives. I have said that chemically it is related to sugar and starch. In fact, it may rather readily be converted into sugar, and this has been done in Wisconsin and the cows that fed upon this food gave increased milk with higher butter fat than when fed upon barley. In South Carolina the Du Pont Company some years ago used the sawdust from three sawmills for treatment by dilute acid and fermenting the resulting sugar to form the ordinary grain alcohol. As the late Dr. Slosson used to say, "It is now possible for a man after he has read his morning paper to get drunk on it."

More intimately associated with our daily life is the cellulose product which, under the name of artificial silk or leather or "Duco," pleases us so much and which constituted a very considerable portion of the Christmas which we have just passed. Until recently it was believed by chemists and manufacturers that only cotton cellulose could be successfully nitrated, but the Germans demonstrated very plainly that the smokeless powder which they made from wood pulp cellulose carried a projectile an even greater distance than cotton cellulose, and soon to an increasing extent we shall use wood cellulose for the great industries that are rising up before our eyes.

When properly manufactured wood pulp is treated with acid, a new product known as nitro-cellulose or cellulose acetate is obtained; or when treated with an alkali and carbon disulfide, a solution of cellulose is obtained. If this solution is squirted out of tubes through extremely minute holes into acidified water, each tiny stream becomes instantly solidified into a silky thread which may be spun and woven like that ejected from the spinneret of the silkworm. The wonderful development of fiber silks, celanese silks and other artificial silks, is well known to this radio audience, and I hope this excursion into chemical industry will not detract from the pleasure of wearing them. History tells us that at one time fig leaves were prominent articles of attire, but now we have advanced to the place where we make use of the whole tree in order to be properly clothed in silken apparel.

Not only are we dependent upon cellulose for the decorative effect of our clothing, but our automobiles have greatly improved their appearance under a glossy coat. Formerly the pride of the auto salesman consisted in telling his prospect of the eight or ten coats of oils and gums which had been carefully brushed and rubbed over the surfaces and how finally these coats were baked in an oven. Now we take cellulose, nitrate it and dissolve it in a quick-drying liquid, add some coloring, and after the painter has put on his gas mask, he quickly sprays the solution of cellulose and pigment upon the properly prepared surface of the automobile. In a few hours it will have dried without giving a chance for the dust and millions of flying gnats of the atmosphere to settle on it. Or the solution may be spread upon a cellulose fabric such as canvas to make a substitute for leather, which we use for auto tops and curtains, or for elegant flexible book binding, or to cover the furniture of the drawing room. Even shoes are now made which, as Dr. Slosson used to say, a vegetarian could wear without pain of conscience, for the soles are made from the sap of the rubber plant and the uppers of cellulose-coated fabrics. The live-stock industry will soon have to do double-page advertising in the magazines to inform coming generations of the virtues of leather.

These cellulose solutions are making chemists out of every one. The butcher has to ask for viscose tubes for sausage containers; the candy manufacturer buys transparent viscose film under the name of cellophane with which to wrap up his candies; the trunk manufacturer knows that vulcanized fiber made by running sheets of paper through a solution of a zinc salt makes trunks of good quality; and the motion picture theater advertises that acetate films used by them are non-inflammable. These chemical terms are being incorporated into the street language of the day.

I can not conclude without a moment's tribute to my colleagues in science who have made these things come to pass. Because they were interested in searching for new facts, they penetrated beyond the borders of the known and laid open to our gaze these results of their explorations. We have quickly taken them and are now using them and enjoying them.

THE EVER-CHANGING LANDSCAPE

By Dr. HENRY C. COWLES

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When one surveys a majestic forest, with trees several centuries old, one may very likely think that such a landscape is eternal. One speaks of the "everlasting hills"; but geologists have proven that hills are really ephemeral, and by no means everlasting,—though hills usually are ephemeral in a geological sense only, rather than in terms of human life.

Forests, on the other hand, are much shorter-lived than hills. In many cases the human life is long enough to see marked change in the natural plant covering of our hills and valleys. Doubtless many of you have seen a forest cut down and another one, quite different, take its place.

Similar changes take place without human influence, though much more slowly. A pine forest in our northern states, if it has any undergrowth at all, is likely to have an undergrowth of hardwoods. When the forest is cut down the hardwood undergrowth is left free to grow to maturity and thus we have the phenomenon of a hardwood forest replacing a pine forest. The same thing would happen in time if the pine were not cut. Eventually the pines would die of old age and the hardwood undergrowth would then come into its own.

Very different is the situation if the pines are so densely crowded that the shade is too great for undergrowth. When such a forest is cut it is likely to be replaced by aspen and white birch, and the problem at once arises: Whence came the seeds to supply the totally new growth?

Some have thought that seeds can live in the ground for centuries, springing into activity when the chance lies open; but experiments have shown that the seeds of these trees soon lose their vitality. Aspen seeds in particular live only a few days. The cause of replacement of pines by birch and aspen is along quite different lines. Aspens and birches are very common trees in our northern states, and every year they produce their seeds in countless millions.

What is quite as important, the seeds of these trees are scattered easily and widely by wind. Probably there is scarcely a foot of ground in the aspen and birch country which is not supplied every year by seeds of these trees. In most instances these seeds come to nought, but when they happen to fall in areas that have been cut over or burned, they germinate and produce forests.

The foregoing illustrates one of the commonest and most wide-spread of natural occurrences, namely, the phenomenon of plant succession. Plant landscapes are, for the most part, in a process of continual change. Some of these changes are rapid enough for one to get a photographic record of them over a period of years; while others are so slow that a human lifetime scarcely suffices for the observation of much change.

The sand dunes of our lake and ocean shores are among the most dynamic of such landscapes. Even on a single windy day a dune may change its place and form considerably. One of the most interesting cases of the struggle for existence is to be seen in the dunes, where some of our hardiest plants have a bitter fight for life against the sand. Trees like the cottonwood, shrubs like the willow and sand cherry, and grasses like the sand reeds are most successful here, their victory over the sand being due to the fact that these plants are able to send out roots from their shoots if buried, or shoots from their roots if unburied.

Eventually these plants may become abundant enough to cover the dune and prevent its further movement, whereupon a host of plant species may start on the stabilized sand, representing a second stage in dune plant succession. In this second stage there may be juniper, pine, and other plants, varying with the climate and geographic location. These first plants of the stabilized dune are those that require sunlight and can endure dry soil and high evaporation.

As the pines and other trees of this stage grow in size, they cast more and more shade, which in time tends to cause the soil to become more moist and more suitable for shade plants and less and less suitable for pines—so, a situation arises where hardwoods such as oaks germinate in the shade of the light-requiring pines. Thus it is that hardwoods follow pines in natural succession.

Similarly, in many places the oaks may be succeeded by the still more shade-tolerant beech and maple. Since beech and maple seedlings are tolerant of the shade cast by the parent trees, they may develop in such shade without difficulty and thus carry on the same type of forest that existed there before. Beech and maple forests, therefore, may perpetuate themselves almost indefinitely. For this reason such a forest is termed a climax forest.

On clay uplands the succession is much the same as in the sand dunes but without the stress of the first stage. The end is the same and arrives more quickly. On rock uplands the later stages of the succession are the same as on sand or clay. At the outset, however, the stages are very different, the first plants commonly being lichens, which are extremely tolerant of sunshine and drought. These plants build up soil and prepare the way for higher plants, such as the drought-tolerant mosses, which are followed by drought-tolerant ferns and flowering plants. After a long time there may enter a stage of light-requiring trees, much like the first stage on a stabilized dune. Once in a while the succession does not go to the climax because of adverse soil conditions, as in the areas known as sand barrens. Here the succession may stop with a pine or oak stage instead of going on to the beech and maple climax.

Quite in contrast to the above, but similar in principle, is the succession of plant life in ponds. Many ponds are surrounded by symmetrical zones or belts of vegetation that may be considered dynamically as stages in succession. The first stage in a deep pond consists of aquatic plants and animals of various kinds. Upon their death their remains help to build up little by little the pond bottom, making the pond shallower from generation to generation.

After a time the pond becomes shallow enough to support such plants as water lilies. These in turn build up the pond bottom and make the pond shallow enough for such plants as bulrushes and cattails. In similar fashion these are followed by sedges and grasses and in time by trees, such as the willow, ash and elm. So there comes as a climax of pond succession a forest quite similar in nature to the climax on an upland of rock, sand or clay.

The successions noted above are such as may be seen rather generally in our northern central states. Successions similar in principle but differing widely at various points in the successional stages may be found anywhere in the country, or, for that matter, in the world. The phenomenon of succession is one of universal importance wherever plants grow, and may be looked upon as one of the most interesting of the phenomena of nature.

BIRD MIGRATION

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In July and August each year, after the nesting season for our birds is over and young are on the wing, flocks of martins, blackbirds, swallows, sparrows and other species gather at night to roost in some selected grove of trees or bed of rushes, and in morning fly out again over the country-side in search of food. Such roosts, when located in the shade trees of lawns or along city streets, are frequently a serious nuisance as the birds come nightly and can be driven away, if at all, only with the greatest difficulty through bombardment with guns, streams of water from fire hose, Roman candles or other means. In the case of such species as sparrows and starlings these roosts may continue throughout the winter, the only change being from grove to grove, or from trees to church towers and sheltered crevices about buildings as colder weather comes, or as the birds are disturbed by predatory owls or other enemies. With blackbirds, swallows and robins such nightly gatherings are the forerunners of seasonal migrations in which the birds concerned, with a host of other species that do not congregate in flocks, fly southward to warmer regions to remain through the period of winter. In spring they return northward once more to their nesting grounds.

Most of the birds that nest in regions

of Arctic climate, and a majority of those found in the temperate zones, perform migrations of greater or less extent, some of the species concerned making journeys that carry them from the Arctic regions to areas far south of the equator. While we think of migration ordinarily as something peculiar to the northern hemisphere there are many species of birds of the southern hemisphere that after their nesting season move north toward the equatorial regions. Even in tropical countries migrants from a distance pass through so that the naturalist working in the West Indies or in Central America may see warblers, sandpipers or other species in abundance that have come from North America.

From what has been said it appears that the phenomenon of bird migration is one that may be observed throughout the world and has from this fact been known and discussed by man from the most ancient times. Movements of birds have been correlated with the seasons, and various rites and beliefs have been coupled with them by primitive peoples. Though the migrations of birds have been recorded and studied from the days of Aristotle and other early naturalists to the present and a vast amount of information concerned with the arrival and departure of various species has been accumulated yet there is still little known of the reasons for the movements of birds as a whole. Some have attributed the underlying cause of migration to changes in food supply, others to seasonal change in temperature, to a crowding that has driven birds from their original homes to which they have an inherited desire to return for the nesting season, to a reaction to seasonal change in intensity of light, to shifting of range due to changes in the environment in past geological ages, to seasonal physiological changes in the birds themselves and so on.

After careful scrutiny of all the theories that have been proposed to account for bird migration it appears to the writer that while each may explain the movements of a few species no one theory is sufficient to cover the entire group of birds as a whole. The factor that initiates or starts the present annual migrations of birds is without much question certain physiological changes in the bird itself that have synchronized the season of the year and the life cycle of the individual until they serve as signals to start the bird on its northward or southward movements according to the season concerned. These physiological changes must be interpreted merely as seasonal alarm clocks that awaken the birds to movement. The original basic reasons for migration have unquestionably been different in the many different species concerned so that the underlying cause for migration as we see it to-day must be considered as due to a number of factors, some affecting one group of species and some another.

Man, through his physical clumsiness when compared to active birds, and through his dependence upon organization of his environment to enable him to live, moves from place to place only along certain established lines and through means of transportation that are limited in their scope and have many difficulties in their accomplishment. In contrast, the migrant bird, unencumbered by baggage, flies with few restrictions, finding food and shelter with comparative ease, traveling long distances with little apparent difficulty. The arrival and departure of our robins, swallows and wrens, particularly their return to our yards and grounds in spring, is a matter of pleasant observation on the part of many persons who are pleased to greet these friendly birds on their return from their winter's journeys. True appreciation of the great distances covered by these comparatively weak creatures comes however only to the naturalist traveling in distant countries who, seeing barn swallows crossing the seas that separate the main land masses of North and South America, or finding these birds circling over the open grass lands of the distant Argentine, or coursing over lonely lagoons in little known islands in the West Indies, marvels at the physical capability that carries these and others over such long distances, and puzzles over the necessity and the urge for such prolonged journeys.

Migratory movements among birds are easily understood in their performance in the case of large species as ducks and geese that fly by day and are seen crossing the sky in their northern and southern flights. Weaker forms as warblers, sparrows, flycatchers and other small species perform these travels by night so that they appear and disappear silently between suns, their coming and going frequently seeming a matter of deep mystery.

A few kinds of birds, when once established in an environment suited to their needs, have become wholly sedentary and move about within the narrow limits that suffice to provide them with food. As examples of such there may be mentioned the Carolina wren and our familiar bob-white or quail. There are others, as the blue jay, that are present throughout the year but may be represented in summer and winter by different groups of individuals as the species as a whole is distinctly migratory. Many tropical species living in areas where the temperature is equable throughout the year have regular times for appearance and disappearance, and seem to have regular migrations in that they shift from one haunt to another with seasonal shifts in food supply and other conditions in their chosen environment.

With most birds migratory movements are well known and their summer and winter homes have been recorded and outlined in detail with the dates of arrival and departure.

Some birds that nest in the Arctic tundras, as the golden plover, pectoral sandpiper, and the hunting gulls, or jaegers, in the winter season travel south to South America, or in the case of the jaegers even into Antarctic seas. Many of our warblers, flycatchers and vireos seek winter homes in Central America, northern South America and the West Indies, while bluebirds, robins and blackbirds travel only into the southern regions of the United States. Many of these latter pass only far enough south to escape the most severe weather so that they begin to return with the first warm days that come in February. The length of individual journeys in migration thus varies within wide limits, and in some species of birds that nest at high altitudes in lofty mountain ranges may be confined to a movement of a few miles to the plains about the mountain bases.

A few species of birds travel north after the nesting season to remain in areas north of where they nested and then pass south as cold weather comes. This is true of the snowy heron, the egret, and the little blue heron that nest in the southeastern United States and in late summer move north to the Ohio Valley, southern New England or even into southern Canada. The white forms of these herons appear along the Potomac River near Washington in July, and the birds remain until September in considerable numbers. The Wilson's petrel, or Mother Carey's chicken, rears its young on distant islands in the Antarctic area and in May travels far north beyond the equator through the seas of the world.

One of the most interesting facts in connection with migration is the almost clocklike precision with which it progresses in the temperate zones. Through records kept for long periods of years the average dates of arrival in spring and departure in fall for our common birds are well known, and it is found that they move with astonishing regularity varying only a few days from an average date. More recently through the banding of birds, studies in which living birds are captured alive in ingeniously devised traps, marked with numbered aluminum bands so that they may be subsequently identified, and then released, it has been learned that the individuals of many wide ranging species have definite circumscribed areas for summer and winter homes and that apparently they move between these two along definite routes.

The chimney swift, called by many the chimney swallow, though it is not of the swallow family, resembling that group only superficially in form, in its southward migration gathers in great flocks in fall and is recorded abundantly in its movements south as far as the Gulf Coast of the United States. It then disappears to return the following spring. Years ago this swift was one of the species that, with swallows, the sora rail and some others, was supposed by the credulous to hibernate in a state of suspended animation beneath the water and mud of streams and swamps, and to revive and come to the surface again in spring. This superstition, entirely without basis, has been believed for centuries, and still persists in some localities. As regards the chimney swift, however, in recent years it has been observed in passage in eastern Mexico and in the Republic of Haiti, and it is believed that it spends the winter somewhere in the northern part of South America.

The bristle-thighed curlew, a large shore bird, is found in winter along the sandy beaches of Pacific islands from the Hawaiian group south to New Caledonia. In spring it comes north to Alaska and there disappears to seek some unknown breeding ground in the interior mountains of that territory. One by one however the mystery that has surrounded the homes of such birds is solved, and it will not be many years until the movements and ranges of all temperate zone species will be known.

The subject of avian migration is one of continual interest that will have its major contribution in coming years through studies aided by the bird banding just mentioned, which will finally explain many existing problems. The manner in which birds find their way in their long journeys is still one of the major points regarding migration that may or may not be solved, while the actual origins of our present day migrations, dating back as they must to beginnings in remote geological ages, since even our modern types of birds have been known for millions of years, will remain more or less mysterious. The subject is one that will repay study and consideration.

MARRIAGE AND FAMILY LIFE AMONG THE PLAINS INDIANS

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THE so-called savage tribes of the world are not like undisciplined hordes of apes. They do not live only to gratify their animal instincts. On the contrary, all their behavior is regulated by strict standards. The aborigines of Australia are among the simplest peoples on record, but neither in hunger nor in love do they act like the wild beasts of the forest. They abstain from what they consider delicious food because their elders so command, and they seek mates only from a definite class of girls or boys, respectively. In the old days breaking either of these rules would have been considered most immoral, and any one marrying the wrong person would almost inevitably suffer corporal and often capital punishment.

What is true of these crude Australians holds in a general way for the Plains Indians of North America—the Sioux, Cheyenne, Crow, Blackfoot, Omaha and other buffalo-hunters. They did not control individuals by the laws of native Australians or citizens of the United States. But they had quite as fixed ideals of behavior, and a man's standing in his community depended on how closely he realized these standards in his personal life.

In some respects the practice of the Plains Indians resembled that of England under Queen Victoria. There was a double standard: women were expected to be virtuous, men to be gay blades. On the other hand, women who failed to live up to the highest standards did not become outcasts; they merely lost prestige and were barred from certain sacred ceremonies. Society was more charitable. It was also less hypocritical: the men did not profess a lofty morality which they did not practice.

Whatever principles, however, *were* accepted commanded unquestioning obedience. Blood-relatives did not marry one another, and where there was a clan organization even a tenth cousin or no kinswoman at all would be barred from marriage with a man who bore the same clan name. If a Crow, *e.g.*, broke this rule—a thing that hardly ever happened —he would not indeed be jailed or flogged or killed as in Australia, yet his punishment was severe from the native point of view. He lost standing in the tribe and was publicly exposed in songs poking fun at him at the very occasions when he wanted to make a grand showing. Even where clans were lacking, the norms were equally strict. If a young Cheyenne girl found that one of her suitors was related to her, no matter how remotely, she at once discouraged further attentions, and the young man would be greatly mortified to learn of his mistake.

How did a Plains Indian get a wife? One way was to elope with the girl of his choice, who was most frequently wooed while fetching water for her family. But such love matches, while not necessarily disgraceful, were rated as inferior. The proper procedure was for the suitor to offer property to the parents or brother of his choice, and these might accept or spurn the gift. At first blush this seems degrading to womanhood; the bride appears to have no say in the matter and to be treated as a chattel. But this is an unfair judgment. Indian girls were rarely forced into unions that were absolutely repugnant to them. They were guided by their parents for the same reason that white girls were guided by theirs a hundred years ago. Being married off at an early age—puberty—they were quite correctly believed not to know what was good for them. It is true that the parents in neither case know any better but they could not be expected to realize that. As for the idea of *buying* a wife, that was the greatest honor for the girl. If a young warrior risked his neck to capture ten head of horses he might offer as her price, it showed how much he valued her personality. He would not dream of making such an offer for a young woman who was not both chaste and competent. Then, again, there was generally rather an appearance of purchase than the reality. The girl's kin often gave back as much property as they received. The significant thing was an *exchange* of gifts between the two families. That exchange marked their sanctioning the new bond and cementing a relationship between two *groups* rather than two persons. The idea is still in vogue when a royal European prince marries in the interests of the State.

This notion that the *family* is mainly concerned in marriage—not the individual—explains two very wide-spread customs. They held sway not only among our buffalo-hunting tribes but also in many other areas, in fact, they are recorded in the Bible. If a man died, his widow was often taken by a brother or cousin of the deceased. This evidently would maintain the old tie between the two families. Also, if a man took to wife the eldest daughter of a household, he often married her sisters also as they came to be of age. The Indians sometimes say that this is the way to enjoy polygamy without quarrels between the wives.

No woman felt disgraced by this or any other form of polygamy. However, polygamy could not be general for the simple reason that there were not enough women to go around. Hence, only the distinguished men could have two or more wives.

It might be supposed that where marriages were arranged by parents and where a wife could be inherited from an older relative, no such thing as true love could blossom. This is a grave popular error. Deep affection united many husbands and wives. There are even cases of "romantic love" among our Plains tribes. In the traditions that mirror their social life, we find cases of true devotion, a woman going alone through hostile territory to rescue a crippled lover; a man, who like Orpheus in Greek myth, follows his dead wife to the land of spirits.

There is another popular fallacy that an Indian wife was a much abused drudge. It is true that Plains women were more constantly employed than men, for they managed the daily routine. It was the wife's business to pitch and take down the tent, arrange the inside, cook food, fetch wood or water, dress the skins of animals and make clothing and containers out of them. The men did sometimes spend whole days in leisure. When they did work, however, their tasks were more arduous and either hunting buffalo or raiding the enemy was a dangerous job. As for maltreatment, an unfaithful wife might be severely mauled or even disfigured in some of the tribes, but generally a man was looked down upon if he abused his wife without strong provocation.

Children were dearly loved and coddled by their parents. The idea of beating them was very repulsive to the Indian mind. A white trader who lived with the Assiniboine for over twenty years never saw a man strike his child. Education proceeded along vocational lines, *i.e.*, parents gradually taught their offspring the pursuits of later life.

Some quaint ideas shaped Plains Indian family life. A Crow or Cheyenne was not permitted to talk to a grown-up sister; only as children were brother and sister allowed to play and chat together. Still stranger is the wide-spread rule—also found in Australia and Africa—that a woman must not speak to her son-in-law nor he to her, a rule which still survives. This has nothing to do with our mother-in-law jokes, but rests on a deep sense of mutual esteem. If a woman spoke to her daughter's husband, it meant that she had no respect for him.

These rules of etiquette surely make Indian family relations different from ours. But odd as they appear to us, they show refinement rather than brutality. They prove that social intercourse was not left to instinct but was strictly regulated by social norms. The Plains Indian was a stickler for the proprieties as he understood them. Neither as a lover nor as a spouse nor as a parent was he anything like the savage of popular fancy, but rather a human being like ourselves who happened to work out somewhat different standards of behavior while displaying much the same sort of human sentiments.

BEAUTY AND THE SCIENCE BEAST

By Dr. J. O. PERRINE

MONTCLAIR, N. J.

MANY clergymen, novelists, artists, poets, musicians and philosophers proclaim that the present era is lacking in appreciation of the beautiful and cultural. They bemoan the stifling and baneful influence of machines and science. They deprecate the last quarter century as debasingly materialistic, devoid of spiritual values. The pulpit and the writers of magazine articles would have us believe that only poems, songs, flowers, music, running brooks, waterfalls, mountains, the sea, ancient castles and ancient cathedrals are beautiful; that science is sinister, crushing and unlovely. Furthermore, the poet and his confrères boast of having a monopoly of beauty; they arrogate to themselves the possession of a patent on the spiritual and divine appointment as custodian of things cultural.

It seems to the scientist that beauty, after all, is of two kinds, macroscopic and microscopic. The poet's, the artist's, the clergyman's notion of beauty is macroscopic; to the scientist, beauty is microscopic. The poet enthuses over beauty as an overall attribute, as a composite of line, curve and color: a sunset, a forest primeval, a symphony, a Grand Canyon, a something of great proportions and awe-inspiring majesty; his is a general, a far-off, a long-distance view; he is a macroscopist. The scientist sees beauty in the individual item: in line, tone and color *per se;* an electron, the strength of a single wire among thousands which support a bridge across the Hudson River, the making of a glass stain to last for centuries in the windows of a Cologne cathedral; his is a particular, a close-up view; he is a microscopist. Those aggregates of line, curve, color and tone, which appeal to the eye and the ear, are the delight of the poet. His senses prompt him to write "A thing of beauty is a joy forever." That beauty of curve, color and tone exist is accepted by the scientist, but with his intellect he seeks to understand the "how" and the "why" and the "how much." Therein lies beauty for him. The poet sees a chapel at Trinity College, hears a Philharmonic; the scientist sees and hears, but facts and principles, inarticulately present in his mind, give him joy of a different kind.

The poet is prone to feel that detailed knowledge does not add to one's appreciation of the beautiful. He thinks this way because his sense of beauty is macroscopic. He says, "When Kreisler and Paderewski are playing, who wants to think of catgut and varnish and Stradivarius, and overtones, vibrations, steel wires and Helmholtz?" The scientist delights in thinking that from catgut and varnish and wood and steel, man evolved instruments on which man can play so charmingly. A subconscious recognition of the sheer mechanics of the artistry, an understanding of frequencies, vibrations and elasticities, afford a different sort of appreciation. Then, too, the scientist's mind tingles when he thinks of this same music's being carried to thousands who can not be in Carnegie Hall to hear with their own ears. Microphones, wires, coils, glass bulbs, all connected with leaden batteries, reproduce golden tones, because scientists like Helmholtz studied microscopically to bring about a result whereby poets in Indianapolis may listen macroscopically.

There need be no controversy as to

which type of beauty is more beautiful; each has its devotees; to each group its brand of beauty is very real and satisfying.

"When I consider the heavens, the work of Thy fingers, the moon and the stars which Thou hast ordained" was the poesy of a macroscopic psalmist. To gaze into the heavens and wonder and wonder and do nothing about it is one thing; merely to see Halley's comet streaming across the heavens is one thing; to concern oneself with the details of the heavens, with nebulae, with distances measured in light-years, is another thing. To understand the precision with which the planets speed along in their orbits; to think with Copernicus; to know that red stars are older than blue stars; to predict that Halley's comet will reappear at a specified hour, day and year; these facts, these achievements of man's intellect, these microscopic concepts are of themselves comparable in beauty to those of the psalmist; they add rather than detract.

A few years ago a poet, generically speaking, wrote as follows: "The best Christmas gift that has ever been given to North America is the establishment of friendly relations between the United States and Mexico by Lindbergh's flight. The reason for this is that Lindbergh has captured the imaginations of all people and has therefore gotten beyond cold scientific facts. The loveliest things in life are not scientific." What a foolish poet, what a narrow macroscopist, if such an antithetical phrase is tenable. Perhaps the imaginations of many people do not get beyond cold scientific facts; that is the way of most people. Fortunately, others have gotten deep into cold scientific facts—the Wright Brothers, Langley, Curtis, Lawrence the engine designer, oil chemists, geologists, experts in thermodynamics—all of them microscopists. Lindbergh's plane might have been made quite beautiful, in accordance with poets' standards, by having a modern artist paint an eagle on the fuselage, as Raphael painted a Madonna on the head of a wine barrel centuries ago. However, that kind of beauty would not have carried him to his goal. He sought every possible bit of fact, made most careful preparations, and his compass, altimeter, bank indicator, gauges, thermometer, tachometer and other microscopic beauties revealed to his intelligence, not his emotions, the required cold facts necessary to steer his way through darkness by night and above clouds by day. A flight to Mexico, a flight across the Atlantic; a telephone call from San Francisco to New York by wire, thence by radio to the Majestic in mid-ocean; a great locomotive speeding through a Moffat Tunnel; these are not accomplished because winds are favorable, electricity is docile, steam is tractable or rocks are soft. Accurate information as to whether the wind is propitious; how electricity and steam may be made to serve; sheer precision and analytical methods; these attributes of science are the factors responsible, and in them there is much beauty. The scientist agrees with the poet that the loveliest things in life are not scientific. However, they possess their loveliness in many, many instances because of science.

Flowers and children, all agree that they are beautiful. "Consider the lilies, how they grow. Solomon in all his glory was not arrayed like one of these."

> I met a little cottage girl:
> She was eight years old, she said;
> Her hair was thick with many a curl
> That clustered round her head.

The poet says: "Don't pick the lily to pieces; don't think of its stamens and pistils, its leaves; don't destroy it; just look at it and be charmed by its beauty." If a lily is blighted, he says "How sad!" He may write a poem about it. The botanist analyzes. He considers how the lily grows and he studies plant diseases. If a field of lilies is blighted, he studies the blight. More lilies, and more beautiful, result from his understanding. The chemist, another microscopist, learns how to prepare the soil to better grow lilies. He and the botanist see beauties unknown to the poet. They have not impaired beauty by analysis. They have multiplied beauty.

Vitamins! What an achievement for the microscopist! Mother love is beautiful, but not sufficient in itself to restore health to a sick child. For generations and generations, children and mothers have been admired and written about and extolled by poets, novelists and parsons. Such macroscopic admiration never saved a child's life or restored one to health. Vitamins, literally a product of test-tube, analysis, microscope and cold scientific fact, help make sound bodies for sound minds.

A vial of insulin may not possess the color of one of Wordsworth's daffodils or the fragrance of one of MacDowell's wild roses, but it does give life, and, after all, to have life and have it more abundantly is most beautiful. To see the beauty in a vial of insulin, one must look deep and look imaginatively. Insulin is, because a scientist studied dumb animals microscopically and found another kind of beauty than is seen in pictures of them by Paul Potter.

Some years ago, France made an appraisal of its famous men and women. Among those in its Hall of Fame the greatest was to be chosen. Who was chosen? A novelist? A statesman? A soldier? A painter? No. A microscopist, Pasteur. Mindful of the good he had done and the happiness he had given to the world, the common folk acclaimed him the greatest. If one were to be added to the list, perhaps that of Madame Curie would be added. Madame Curie, microscopist of microscopists. Bacteria—tiny and invisible. Radium—tons and tons of ore to produce a tiny speck of radium, from which the tiniest of tiny rays radiate with healing in their wings.

It is a custom in the United States to use superlatives. Bobby Jones is the greatest golfer of all time. Other greatest of the greats have been named. What if we would do as France did and seek the greatest of our great men. Would he be a statesman, a poet, a surgeon, a painter, a preacher, a soldier, a novelist, a musician or a scientist? Would he be a macroscopist or a microscopist?

The smokestacks, coal piles, whirling electric generators, spray ponds and boilers, which go to make up a great electric light and power station, are not generally regarded as suitable subjects for polite and cultured conversation. However, to discuss the irregularities of French verbs, the use of the subjunctive by Shakespeare, the prevalence of red in Louis XIV furniture and similar recondite topics, is at once to identify oneself as a cultured guest. To know about or even be aware of the existence of a physical structure that sends out light to make homes cheery and attractive, that sends out heat to make homes comfortable, that sends out power to factories where men can work to make a living; that is a breach of good form, according to the poet's concept of culture. The scientist's, the microscopist's, sense of culture prompts him to say that to be ignorant of contemporaneous factors which help make life healthier and happier on the purely physical side is to lack culture of the finest and broadest type. To be well versed in Plato, the Renaissance, English lyric poetry, transcendentalism and modernistic art, and not have the slightest idea of or concern in those things (the word "things" being used advisedly) which enable man to enlarge and enrich his life, is equally as uncultured as he who lives by bread alone.

In "Les Misérables," Victor Hugo relates an interesting conversation between the bishop and his gardener. The gardener has made plans for the garden and says to the bishop, "Here, I will plant cabbage; there, I will plant carrots; yonder, I will plant lettuce." After plans for the garden have been completely described, the bishop remarks, "But you have left no place for flowers." The gardener replies, "We must not waste any land for flowers; they are not useful." The bishop rejoins, "The beautiful is as useful as the useful; at times, more so."

The scientist subscribes to this epigram of the bishop, and is not one of those who believes money wasted when it is used for cathedrals, symphony halls, art galleries, libraries and parks. However, the scientist desires to point out to the poet, the artist and the bishop a corollary: "The useful is as beautiful as the beautiful; at times more so."

A poet has said, "When we see something beautiful, then we worship." The scientist says, "When one sees something beautifully useful, then it is also time for worship."

Much is said and written about world progress and development. There have been many contributory factors in the past and there will be many different factors in the future. Science and the microscopist will do much in the realm of detail and analysis in doing the work of the world and in making it a better place in which to live. The macroscopist will continue to write poetry, paint pictures, preach sermons and write music, but with all will not have a corner on beauty and culture, nor on things of the spirit.

THE STARS ON OUR FLAG

By AUSTIN H. CLARK

U. S. NATIONAL MUSEUM

FROM the bottom of the sea instead of from the sky came the stars that represent the states upon our flag, if it be true, as is commonly believed, though by no means proven, that the idea of the stars and stripes was suggested by the coat of arms of the Washingtons of Northamptonshire. Furthermore, these stars, originally formed at the bottom of the sea, for millions of years lay buried in the earth before they were first seen by the eye of man.

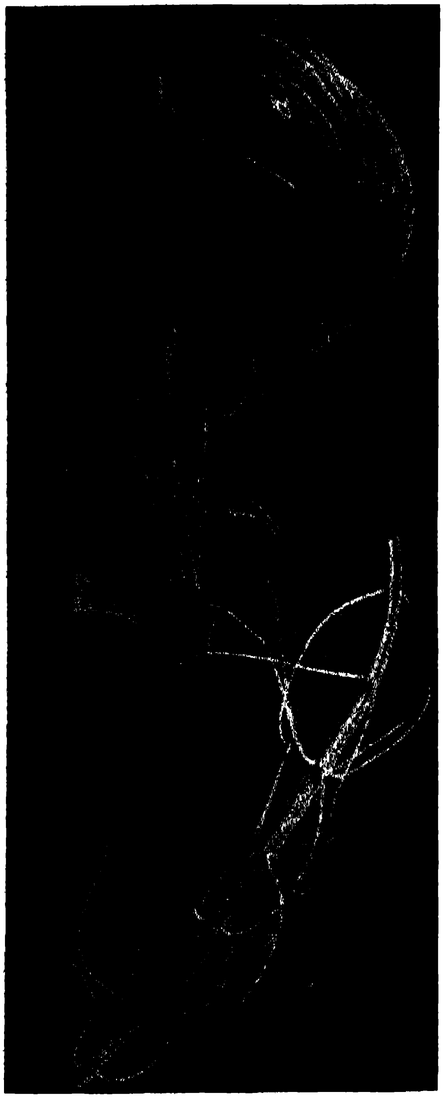
THE WASHINGTON COAT OF ARMS

On the surface of the soil in the Midland shires of England there are often found little five-sided or star-shaped stones which are beautifully and intricately sculptured on the two flat sides. Similar little stones are found in many other places. Sometimes these little stones are circular instead of star-shaped. The central hole permits them to be strung like beads, and in ancient times they were often used for rosaries. They are locally variously known as St. Cuthbert's beads, rosary beads, giants' tears, fairy stones, wheel-stones, star-stones, entrochites and asteriae.

Wherever they are found these little stones always attract attention. Their regular form and exquisite sculpture set them quite apart from all other kinds of stones. Usually they are regarded, or were regarded in the past, with superstitious awe as something supernatural, or at least uncanny. This was especially true of the star-shaped stones.

Because of the superstitious awe with which they were regarded by the common people the star-shaped stones quite naturally appeared upon the coats of arms of the important families in the regions where they are to be found.

In the language of heraldry the star-shaped figures representing the little star-shaped stones are known as *mullets*.



A LIVING CRINOID

WITH A STEM COMPOSED OF AN IMMENSE NUMBER OF PENTAGONAL AND STELLATE JOINTS; FROM THE CHINA SEA IN DEEP WATER.

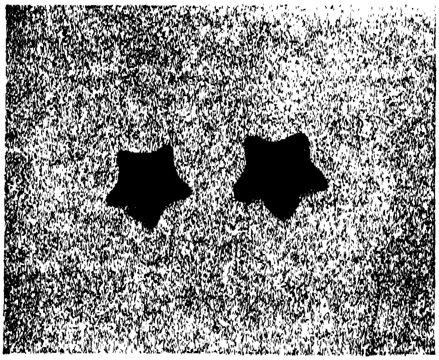
Just as the little star-stones may either have a central hole or be without one, so the heraldic *mullets* may be simple stars or stars with a central hole known as *pierced mullets*.

The word *mullet* is derived from the French *molette*, a diminutive of the Latin *mola*, a millstone, used for various wheel-like objects. In heraldry the *mullet* is one of the common marks of cadency, and is used to indicate the third son.

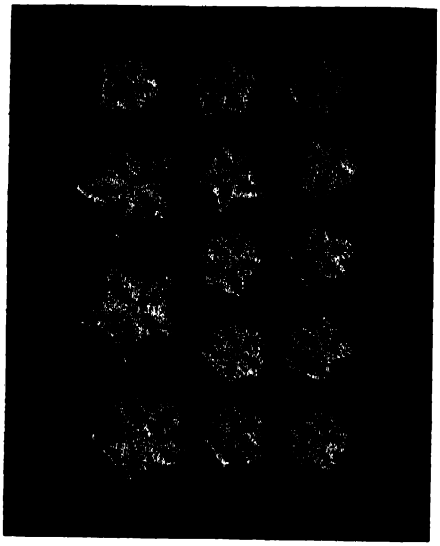
The coat of arms of the Washingtons is technically described as "argent, three bars gules, in chief three mullets of the second." In other words it bears three figures representing star-stones.

Now just what are star-stones? Star-stones are the detached and isolated joints of the long stems of peculiar creatures called crinoids or sea-lilies that live on the bottom of the sea. They are related to the common star-fishes found along the shores. The star-stones in the soil have come from sea-lilies that in the far distant past lived upon a sea bottom which has been turned to stone and is now lifted above the surface of the sea. They have been freed from the rock and separated from each other by the disintegration of the rock through the action of rain and heat and cold.

There are very many different kinds of sea-lilies, and some of them in certain places are enormously abundant. Because of the fact that these creatures have an unusually heavy skeleton they are readily preserved as fossils, and great numbers of fossil kinds are known. Usually the most solid portion of the creature is the stem, which may be many yards in length, so that crinoid stems



STAR-STONES FROM FRANCE



STAR–STONES

FROM A LIVING CRINOID DREDGED IN DEEP WATER IN THE PHILIPPINES.

and stem-joints are among the commonest of fossils.

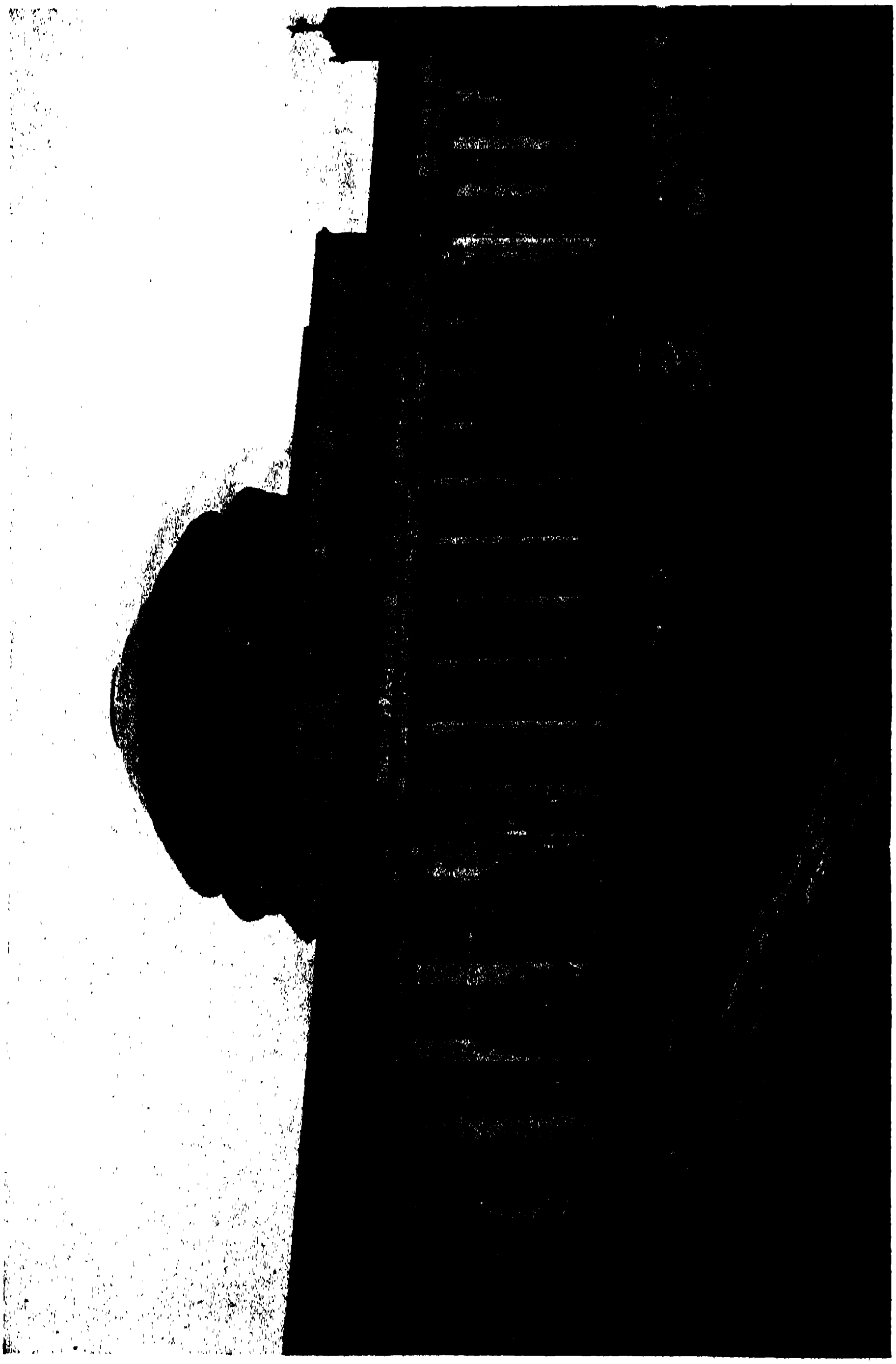
From the present seas we know between six and seven hundred different kinds of crinoids, and of course many more remain to be discovered. They live in all seas everywhere, and are found from the tide pools down to 17,400 feet, or about three and one-third miles, beneath the surface. Most of the still living kinds have stems only when young, at a certain age discarding them. But about one hundred kinds keep their stems throughout their lives.

Those that keep their stems have stems of various kinds, with the joints long or short, circular, pentagonal, or sharply star-shaped. At the present time those with star-shaped stem-joints are to be found only in the Caribbean Sea and Gulf of Mexico, among the Malayan Islands, and along the coasts of eastern Asia.

In North America star-stones are known only from a few localities in the west and extreme northwest, and are quite uncommon.

The history of the stars upon our flag, which have risen slowly upward from complete obscurity in the ocean's depths to the surface of the land and have then been raised aloft, is curiously parallel to the history of the great idea—representative democracy — completely suppressed in early times, then dormant in men's imaginations, now raised aloft and in full flower, upon which our government is based.

This history, however, assumes a definite connection between the stars and stripes upon our flag and the mullets and bars upon the coat of arms of the Washingtons, for which there is no real evidence. In the history of the flag the stars are referred to always as stars, never as mullets, though their form is exactly that of the heraldic mullets.



THE MASSACHUSETTS INSTITUTE OF TECHNOLOGY

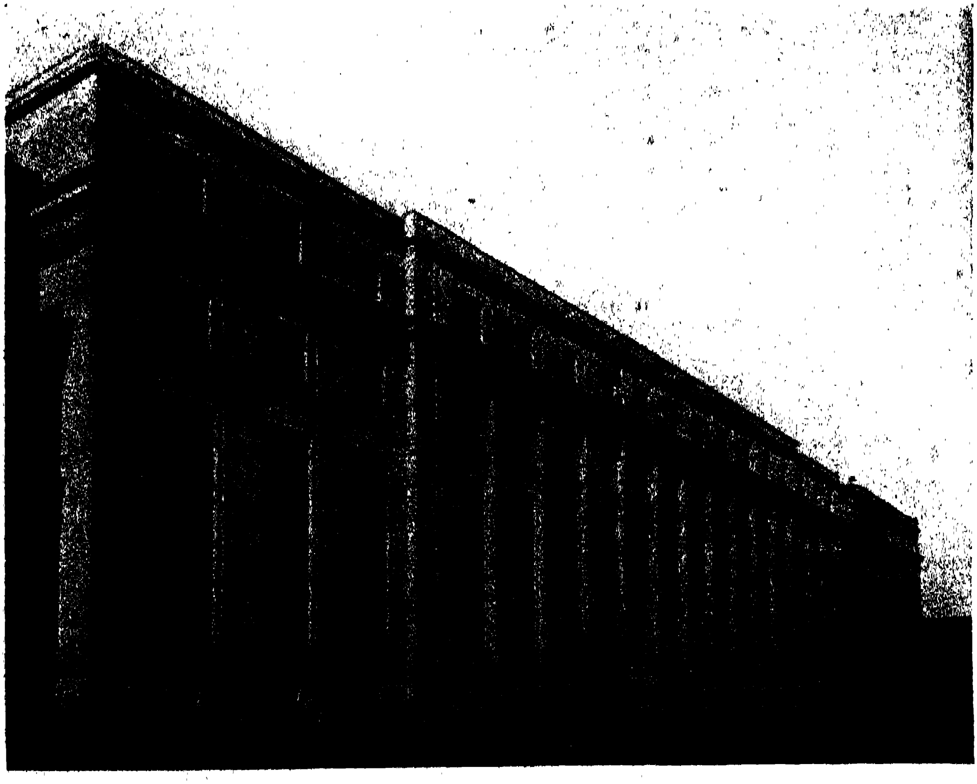
THE PROGRESS OF SCIENCE

THE NEW RESEARCH LABORATORIES AT THE MASSACHUSETTS INSTITUTE OF TECHNOLOGY

REALIZING that the law of physics and chemistry are the basis of engineering, and believing that the future will see great advances in the art of applying science to human welfare, the Massachusetts Institute of Technology has taken a significant step in preparing for these developments by the building of new research laboratories for physics and chemistry. Being built from a fund provided by Mr. George Eastman, these laboratories are named "The George Eastman Research Laboratories."

The main laboratory is a building 300 feet long, varying from 60 to 75 feet in width, and five stories high, including basement. One half of this building is assigned to advanced work in physics and the other to advanced work in chemistry. Adjoining and connected to the physics side of the main building is a specially designed spectroscopy laboratory about 100 by 60 feet and two stories high. The buildings are faced with limestone and are of reenforced concrete construction.

These laboratories have been designed with great care to minimize disturbance



THE GEORGE EASTMAN RESEARCH LABORATORIES

NEARING COMPLETION WHEN THIS PHOTOGRAPH WAS TAKEN IN MARCH.

GEORGE EASTMAN

WHO PROVIDED THE FUNDS FOR THE LABORATORIES, BUT DIED BEFORE THE BUILDINGS WERE COMPLETED.

from vibrations arising either within the buildings or transmitted from the outside. The entire spectroscopy laboratory and also several research rooms for physical chemistry are enclosed by thick layers of cork for heat insulation. This is so effective that the most violent changes of temperature would not affect the inside of the rooms by a rate of more than 1 degree in about three months. Special temperature controls and air-conditioning arrangements are provided.

Two features of the new laboratories are deserving of special mention. One is an unusually adequate and convenient arrangement of a departmental library for physics, chemistry and mathematics, with a reading room, stack rooms and a large number of small cubicles with desks for study in the stack rooms. Adjoining this library are a series of small offices for men engaged in research work of a theoretical nature.

The second special feature is a very attractively furnished social room with an adjoining kitchenette, which has been made possible through the generosity of Mrs. Forris Jewett Moore, and is designed to make the study of chemistry and the allied sciences more attractive. This room will serve as a social headquarters for the advanced students and faculty of the chemistry and physics departments, and will thus provide a type of educational contact which is coming to be recognized as very advantageous.

With the aid of these splendidly designed and equipped laboratories, the Massachusetts Institute of Technology hopes to make a significant contribution to the future development of pure and applied science.

KARL T. COMPTON

THE BATTELLE MEMORIAL INSTITUTE

A MEMORIAL laboratory endowed with sufficient funds to carry on an extensive program of research in the fields of metallurgy and fuels and yet offering facilities for research sponsored by industry or individuals is indeed a unique institution.

The possibilities of such an institution were conceived by Gordon Battelle, a young industrialist who died in his early forties a number of years ago. By his will he established Battelle Memorial Institute as a research institute directing that it specialize in metallurgy, fuels and allied fields. He also directed that it be staffed with experts in the chosen fields and equipped to conduct a program of research on its endowment funds, and have facilities for research by others available at nominal cost well within the reach of all.

His idea of such a dual functioning was well founded. It enables the staff to have the direct broadening contact with industry that is essential to good work in these fields. Without such contacts any group is apt to become ultra-scientific to the point of overlooking the more practical aspects of research. It is because of these features that Battelle Memorial Institute has been said to be among the ideal institutions for research in this country.

The memorial research laboratory, completed about a year ago, is modern in every respect and provides some 90,000 square feet of floor space especially designed for the purpose intended. The architecture is of the Roman Ionic type effected by a pleasing combination of brick and limestone. The building is located on King Avenue adjacent to Ohio State University where contact with the scientific atmosphere of this institution is helpful.

The first floor of the front section of

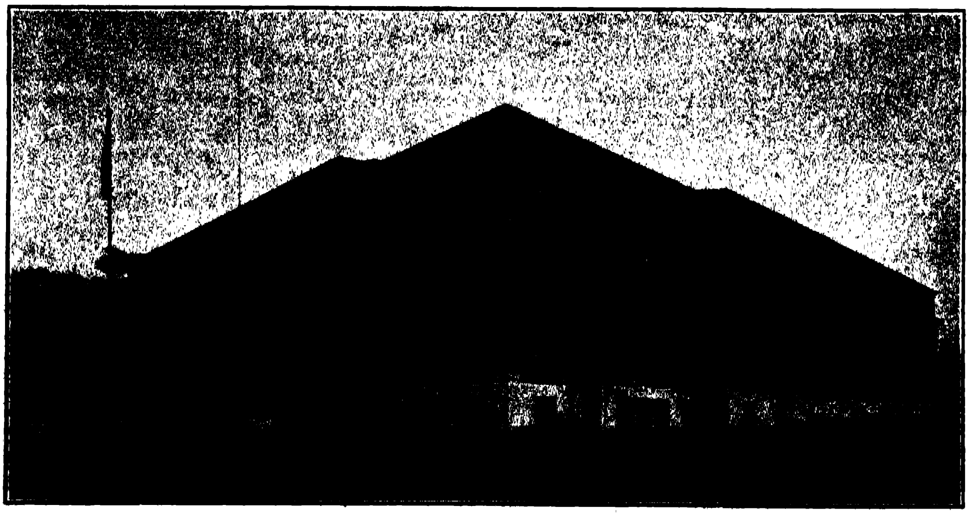
the building is memorial in character with spacious entrance and lobbies done in beautiful architectural treatment with polished marble walls and bronze fixtures. The balance of the dignified structure is devoted to the practical operation of research work. The equipment, which is constantly being added to, is of the most up-to-date type. The equipment purchases are oriented in relation to the projects carried on by the institute as well as to those sponsored by industry.

The institute's staff has rapidly grown in the past year to a total at the present time of sixty, the technical staff being specialists in various phases of metallurgy, fuels or allied fields.

The response from industry and individuals during the first year of actual operation has well demonstrated the fact that the facilities at Battelle Memorial Institute are in active demand and its capacity for industrial work will soon be taxed if the present rate of growth continues.

The following projects, sponsored by industry, are in progress: Endurance properties of special steels; research on the beneficiation of low-grade iron ores; research on cast iron; special developments for the use of metal foils; research on bearing metals; research on alloys for the production of thin metal sheets; research on thermal properties of metal; editorial work on "Metals and Alloys"; research on metal roofing materials; study of embrittlement of structural steel in galvanizing.

Eight of the major projects supported in whole or in part by the institute funds are indicated below: Centrifugal methods of metallurgical analysis; combustion of pulverized fuel; low-temperature properties of aircraft material; low-temperature carbonization of coal (cooperative with Engineering Experiment Station, Ohio State University); alloys of iron research (codification of known information and preparation of monographs, cooperative with Engineering Foundation and ten technical societies); miscellaneous nitriding problems; constitution of hydrocarbons; effect of coal ash on refractory brick (cooperative with the American Society of Mechanical Engineers and the U. S. Bureau of Standards).



THE BATTELLE MEMORIAL INSTITUTE IN OHIO

THE ENTRANCE HALL

THE LIBRARY

MAX VON FREY

MAX VON FREY

Max von Frey, professor of physiology and director of the Physiological Institute of the University of Würzburg, died at Würzburg on January 25, 1932. Born at Salzburg on November 16, 1852, he was thus in his eightieth year; and although in poor health he continued his researches and lectures until a few weeks before his death.

After completing his medical studies von Frey was associated with Karl Ludwig at Leipzig and E. Hering at Zürich. In 1899 he was called to Würzburg to be the successor of Adolf Fick.

The investigations of von Frey fall into three periods. An early period of study of the mechanics and metabolism of muscle, which, begun as a student, was continued until the results justified inclusion in Nagel's Handbuch der Physiologie, under the title "Allgemeine Physiologie der quergestreifen Muskeln." One important observation of this early research was that lactic acid could be oxidized in the liver. The use of physical methods in physiological investigation was keenly appreciated by him. Thus, in the second period, he employed such methods in prosecuting studies of the circulation, the results of which are contained in a monograph "Ueber den Puls," which he dedicated to his teacher, Ludwig.

From 1895 to his death he was engrossed in the problems of cutaneous sensations, his life work, and a phase of physiology with which his name will always be associated. He was intensely interested in the skin as the boundary between the organism and its environment, and in the manner in which the environment impresses itself upon the organism through the nervous pathway. Employing stimuli of just threshold value, he demonstrated that the various sense spots were discrete elements. As early as 1895, on purely logical grounds, he indicated that the end-organs of Krause were associated with sensations of cold, those of Ruffini with warmth. He demonstrated the existence of a deep pressure sense and showed its significance in an appreciation of posture and movement. The results of these investigations upon cutaneous sensations of von Frey and his students are contained in thirty volumes of "Arbeiten aus dem Physiologischem Laboratorium der Würzburger Hochschule."

In the "Vorlesungen über Physiologie" the materials and methods of many years of instruction of medical students are woven into a volume which has the merit of clarity and brevity without the sacrifice of essential material.

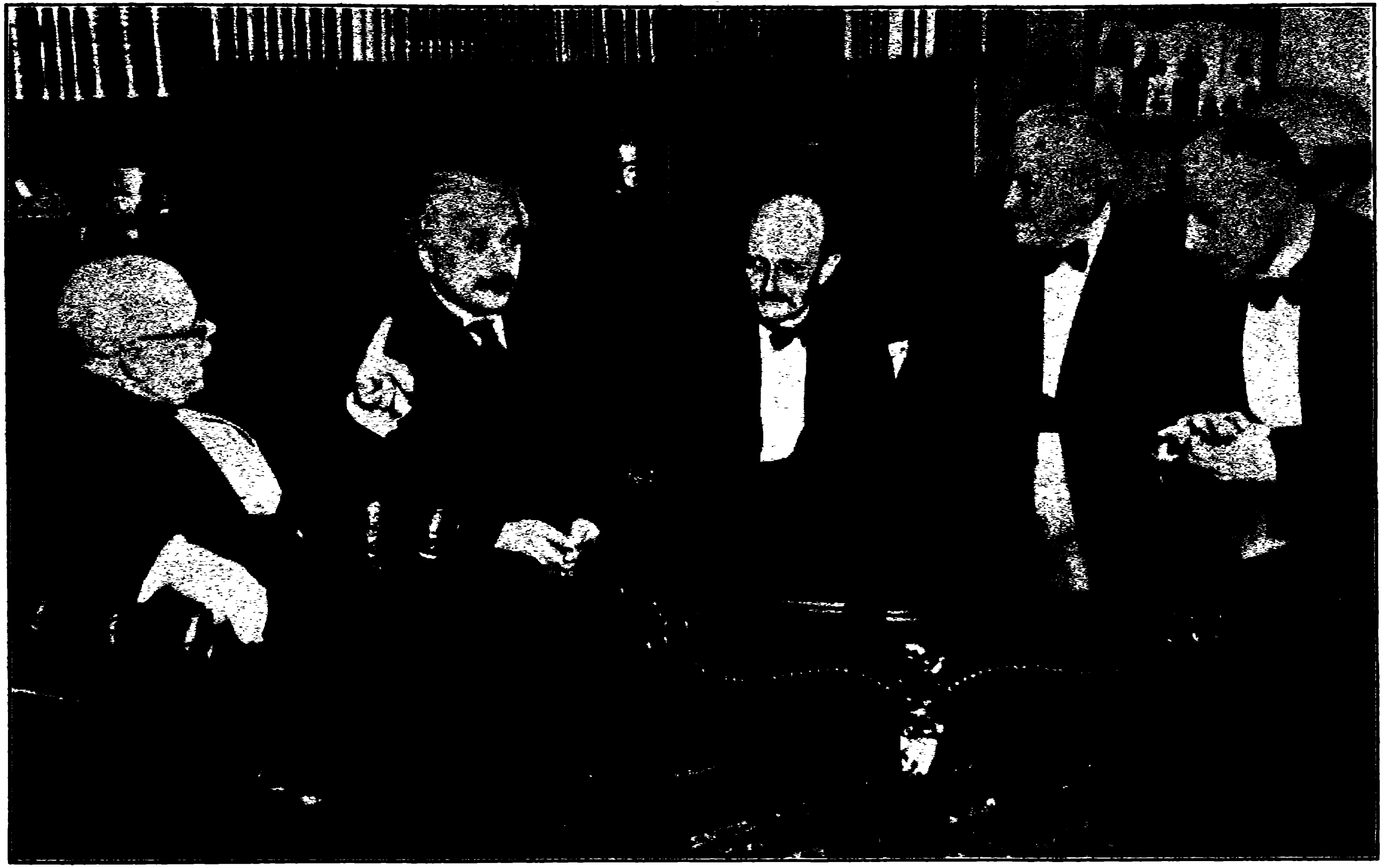
In the conduct of his own researches he imposed upon himself the necessity of a high degree of accuracy and exactness, and the conclusions he drew were only those that were warranted by the results of the experiments. He demanded of his coworkers the same carefulness and accuracy. As a result of his training many of his former students fill responsible positions in the German universities.

In both appearance and bearing, Professor von Frey was very dignified. Although somewhat reserved, his students knew that his was a kindly and warm nature. He was interested in the welfare of his assistants as well as in their research problems, and it was always possible for them to seek advice of him. Those American students who sought permission to study at his laboratory were certain of a warm and generous welcome.

A master of his subject, a seeker for the truth, a great teacher has passed.

Bartgis McGlone

Würzburg, Germany



GUESTS AT A DINNER IN BERLIN GIVEN BY PROFESSOR VON LAUE TO DR. MILLIKAN

PROFESSOR WALTER NERNST, PROFESSOR ALBERT EINSTEIN, PROFESSOR MAX PLANCK, DR. ROBERT A. MILLIKAN AND PROFESSOR MAX VON LAUE.

WEIGHING THE ATOM

A NEW precision mass-spectrograph, the instrument by which physicists actually weigh individual atoms, was described to the members of the American Physical Society at their meeting on February 25 in Cambridge, Massachusetts. The instrument had just been completed by Dr. Kenneth T. Bainbridge, of the Bartol Research Foundation. Until now there has been only one such instrument of high precision in the world, that of Dr. F. W. Aston in England. He was recently knighted for the important discoveries he made with it. The new instrument brings to the American world of physics a research tool of immense value.

In spite of the smallness of the atomic particles, it observes the new mass-spectrograph is a large and complicated construction occupying with its auxiliary apparatus a large portion of an ordinary room. The atoms it weighs are only about 10^{-26} ounces in weight, but the machine itself weighs over two tons. It required nearly a year to build it, and, in spite of every economy in the use of home-made parts, represents an outlay of over $2,000, exclusive of Dr. Bainbridge's time.

The importance of a precision mass-spectrograph lies in its ability to furnish information concerning atomic nuclei—now in the center of the research limelight. It is thus complementary to the researches with high voltages and fast particles now in progress under such experimenters as Professor E. O. Lawrence, in California, Dr. M. A. Tuve and his associates in Washington, D. C., and Dr. Robert J. Van de Graaff at the Massachusetts Institute of Technology. While these observers seek to break down the atomic nucleus to learn its secrets, the mass-spectrograph studies the nuclei as they are.

Many problems await Dr. Bainbridge's attention, but perhaps the most important of these is the determination of the exact mass of the newly discovered isotope of hydrogen. This new kind of hydrogen atom is known to weigh approximately twice as much as the ordinary hydrogen atom. Beyond that fact nothing is known about it, and indeed its very existence was only proved within the last three months by the recently reported experiments of Professor Urey and Dr. Murphy at Columbia University and Dr. Brickwedde at the Bureau of Standards.

When the new hydrogen is available in concentrated form, Dr. Bainbridge will determine its so-called "packing fraction." The atomic nucleus in this case is supposed to be made out of three elementary particles, one electron and two protons. These are expected to weigh a little less in combination than they do when they are separate. The difference is called the packing fraction and it represents the amount of mass which would be lost in making a new type hydrogen nucleus out of its elements.

Out of the Einstein theory of general relativity comes a strong suggestion that mass lost in such atom construction can appear in the form of radiant energy. It would produce rays like the cosmic rays studied by Millikan and others which are now being investigated widely and systematically by Dr. A. H. Compton. Millikan is convinced that this is the true explanation for the existence of cosmic rays; only he has had to refer to the building of rather complicated nuclei partly because he was unaware of the existence of the simple new hydrogen type. The nature and penetrability of the cosmic rays emitted would depend upon the amount of the packing fraction which, in turn, would determine their wave-length. Hence it will not be possible to relate the new hydrogen nucleus to the observed cosmic rays until its packing fraction is determined.

This will be a simple matter for Dr. Bainbridge as soon as he receives a suitable sample of the hydrogen. In fact, his apparatus works best for the lighter elements like hydrogen, and the paradoxical situation arises that single atoms of elements like gold and mercury are actually almost—but not quite—too heavy to be separated and weighed conveniently!

Other chemical elements than hydrogen will come under Dr. Bainbridge's observation, for Aston has shown that most elements consist of a mixture of isotopes, or atoms of different weight, and many elements have not yet been analyzed from this point of view. In the case of these elements we actually have no idea of the weight of their atoms, even though their "atomic weights" have been accurately determined by the chemists. The situation is like knowing the average weight per orange of a bag of a dozen oranges, easily found by weighing the bagful, but not knowing the weight of any one of the individual oranges in it. Only when the individual weights of all the different kinds of atoms of all the various chemical elements are known, will physicists be satisfied. In the 92 elements of a chemists' periodic table, well over 150 different isotopic species have already been found and the search is far from finished. Thus the physicist with his more particular eye discerns a greater variety of atomic bricks of matter than the chemist has needed to take into account.

To explain the operation of the mass-spectrograph in discovering the isotopic constitution of an element or determining the packing fraction of a nucleus, Dr. Bainbridge made the following statement:

"Ions of the elements to be investigated are produced by an electrical discharge through the vapor of the element or a volatile compound of the element or by other means by which one or two electrons can be removed from the outside of the atoms in the discharge tube. The resulting ions are of all different velocities and energies and a wide range of masses, depending on what elements were present. The beam of ions produced in the discharge tube is introduced into a chamber which may be called a velocity filter. The property of this section of the apparatus is to allow through into the final part of the apparatus ions of a definite velocity of all the various masses. The beam of ions leaving this part of the apparatus is introduced into a magnetic field and bent around 180° and brought to a focus on the surface of a photographic plate. The ions describe circular paths with radii proportional to the mass of the ions, so that the heavy ions are focussed on one end of the plate and the lighter ions are focussed on the other end. The photographic plate is darkened at the points of impact of the ions. By careful measurement of the plate it is possible to determine the masses of the ions and hence the masses of the nuclei of the elements with an accuracy of one part in 10,000. By measuring the blackening produced by the ions the relative abundance of the isotopic constituents of an element can be determined. "The actual mass of the material incident on the photographic plate can not be greater than 10^{-12} gram for the usual exposure of a mass spectrum of two or three elements consisting of 5 or 6 atomic species. Exposure times range from 30 seconds to 15 minutes. The energy of the ions ranges from 5,000 to 20,000 electron-volts."

THE SCIENTIFIC MONTHLY

JUNE, 1932

THE ORIGIN OF THE GAMMA-RAYS[1]

By LORD RUTHERFORD
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It has long been known that some of the radioelements emit a penetrating type of x-rays known as the gamma-rays. It is clear that these radiations arising from the nucleus of the radioactive atom represent, in a sense, some of the characteristic modes of vibration of the nuclear structure. The wave-length and quantum energy of many of the stronger lines in the complicated gamma-ray spectrum have been determined by different methods with concordant results. It has been difficult to determine with certainty the origin of this radiation. It was at first supposed that it must arise from the motions of electrons in the nucleus, but in recent years there has been a growing belief that the radiation is connected with the transition of an alpha-particle or proton which forms part of the nuclear structure. It is not an easy matter to distinguish between the various hypotheses since very little is known about the detailed structure of the nucleus. Fortunately, during the last two years, two different methods of attack on this problem have been developed. The first depends on an analysis of the groups of long range alpha-particles which are emitted in small numbers from radium C and thorium C, and the other the analysis of the fine structure shown in the emission of alpha-rays from certain bodies. It may be supposed that the emission of a beta-particle during a transformation causes a violent disturbance in the resulting nucleus, some of the constituent alpha-particles being raised to a much higher level of energy than the normal. These alpha-particles are unstable and after a very short interval fall back to the normal level emitting their surplus energy in the form of a gamma-ray of definite frequency. According to the ideas of wave-mechanics, in this short interval there is a small chance that some of the alpha-particles in the higher levels can escape from the nucleus. On these views, the escaping alpha-particles represent the long range alpha-particles observed and the energy of the alpha-particles given the value of the energy level in the nucleus which it occupied before its escape. Following out these ideas, the long range alpha-particles which escape from radium C have been carefully analyzed using the new electrical methods of counting alpha-particles

Nine distinct groups of particles were observed and the energies of alpha-particles forming each group were determined. The differences of energy between the various groups was found to be closely connected with the energy of some of the most prominent gamma-rays in the spectrum, and, in general, the experiments gave strong evidence that the gamma-rays had their origin in the transition of one or more alpha-particles in an excited nucleus.

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[1] Abstract of a lecture delivered before the Royal Institution on Friday, March 18, 1932.

It has generally been supposed that in a radioactive transformation all the alpha-particles are expelled with identical speed. This is certainly the case for most bodies, but Rosenblum found that the element thorium C emitted not one but five distinct groups of alpha-particles. The discovery was made possible by making use of the great Paris electromagnet in order to bend the alpha-particles into semi-circle. Gamow pointed out that the appearance of such a "fine structure" in the alpha-ray emission should be accompanied by the liberation of gamma-rays.

Owing to certain experimental difficulties it is not easy to obtain a clear-cut decision on this point. Ellis concludes from his experiments that Gamow's view is correct, but Meitner, from similar experiments, reached an opposite conclusion. In view of this difference of opinion, I have made in conjunction with Mr. Bowden, some experiments to throw light on this problem in another way. Recently Lewis and Wynn Williams found that the actinium emanation emitted two distinct groups of alpha-particles differing in energy by about 340,000 volts. It was seen that this observation offered a simple method of testing the theory of Gamow. The emanation was carried by a current of air into a separate chamber and the emission of beta and gamma-rays directly tested. It was found that the transformation of the emanation was accompanied by a weak beta-radiation and a strong gamma-radiation. The experimental results were in good accord with the theory, and thus showed that the presence of a "fine structure" in the alpha-ray emission is accompanied by the emission of gamma-rays. At the same time, the results afford strong corroborative evidence that the gamma-rays have their origin in the transitions of an alpha-particle in an excited nucleus.

It is of interest to consider how far these views can be carried into the region of the artificial disintegration of the elements resulting from the bombardment of certain light elements by alpha-particles. In some of these disintegrations it is necessary to assume that the alpha-particle can be captured in different energy levels, and that a gamma-radiation is emitted as a result of the transition between the two levels. Penetrating radiations have, in fact, been observed in several cases when light elements are bombarded by alpha-particles. Some of these cases are of peculiar interest.

THE RADIATION FROM BERYLLIUM AND THE NEUTRON

In examining the artificial disintegration of light elements under the action of alpha-rays, Bothe and Becker, in 1930, noted that beryllium under alpha-ray bombardment, did not emit protons like boron or nitrogen, but gave out a weak radiation which was more penetrating in character than the gamma-rays from radium. The absorption of this radiation in its passage through matter was later examined in detail by Mme. Curie-Joliot and M. Joliot and by Webster.

It is usual in experiments of this kind

to employ active preparations of polonium on a metal disc as a source of alpha-rays. This source is very convenient for the purpose, as the results are not obscured by the presence of beta and gamma-rays which are so freely emitted from other alpha-ray sources such as radium C and thorium C.

In examining the absorption of this beryllium radiation by the ionization method, Mme. Curie-Joliot and M. Joliot made the striking observation that hydrogen material, when exposed to this radiation, emitted swift protons. In explanation, they suggested that the protons gained their energy by a radiation recoil in a process similar to the well-known Compton effect, and estimated that the quantum energy of the radiation must be of the order of 50 million electron volts.

J. Chadwick, using direct counting methods of great sensitiveness, found swift recoil atoms were liberated not only in the passage of the radiation through hydrogen, but also in other light elements including helium, lithium, beryllium, carbon, air and argon. In a letter in *Nature* of February 27 he pointed out that the results in this and other directions were difficult to reconcile with the hypothesis of a quantum of radiant energy of such high frequency. He suggested that the effects observed were not due to a gamma-radiation at all, but to the liberation from the bombarded beryllium of a stream of swift uncharged particles or "neutrons."

The idea of the possible existence of neutrons, that is, of a very close combination of a proton and electron to form an uncharged nuclear unit of mass nearly 1, is not new to science, but it has been very difficult to find any definite evidence of its existence. Rutherford discussed the properties of such a neutron in the Bakerian Lecture before the Royal Society in 1920, and both the late Dr. Glasson and Dr. Roberts made experiments in the Cavendish Laboratory to test whether neutrons were produced in strong electric discharge through hydrogen, but without success.

It is to be anticipated that a projected neutron would produce little if any ionization in its passage through matter, and would pass freely through the outer structure of atoms. A swift neutron should, however, indicate its presence by the recoil of an atomic nucleus with which it collided. This recoiling nucleus would spend its energy of motion in ionizing the gas, and should thus be readily detected by its electrical effect or by the trail of water drops it produces in a Wilson expansion chamber. In some respects, however, the effects produced by a neutron would be very similar to those due to a quantum of high frequency radiation, and careful experiment is required to distinguish between them.

A discussion was given on the present state of the experimental evidence on this important problem. The velocity of the neutron at the moment of its liberation is estimated to be about 3×10^9 cm./sec., or about one tenth of the velocity of light. By comparison of the velocity of recoil of different atoms, Chadwick finds that the mass of the neutron is about the same as that of the hydrogen atom. In addition, the velocity of recoil of a given atom falls off when the radiation is passed through increasing thicknesses of an absorbing material like lead. This is exactly the behavior to be expected for the neutron, but not for a high frequency radiation.

Very valuable information on this problem can be obtained by photographing the effects due to the passage of this new type of radiation through a Wilson expansion chamber. A number of such experiments have been made by N. Feather and P. I. Dee in the Cavendish Laboratory in association with Dr. Chadwick. For example, it is to be anticipated that the neutron would occasionally collide with the electrons in its path, and thus give rise to an electron track of maximum length corresponding to twice the velocity of the neutron. This is exactly analogous to the well known production of delta-particles by the passage of alpha-particles through gases. Several such short electron tracks have been photographed by Dee which have about the right length, and for which it is difficult to suggest any other explanation. Feather has obtained photographs of more than a hundred recoil tracks produced in an expansion chamber filled with nitrogen. He has observed another very interesting effect. In addition to the straight recoil tracks, he has obtained photographs of a number of branching tracks which indicate that the nitrogen nucleus has disintegrated in a novel way. These branch tracks are believed to be produced by the recoiling nucleus and by some particle which is ejected from the struck nucleus. The identity of this latter particle has not yet been definitely established.

It will take time to analyze the results obtained, and to examine the effects produced in other gases. The peculiar properties of the neutron allow it to approach closely, or even to enter, nuclei of high atomic number, and it will be of great interest to study the effects of such collisions. It is, however, evident that this new radiation has surprising properties, and there is every promise that it may prove an effective agent in extending our knowledge of the artificial disintegration of elements. It will, for example, be of much interest to decide whether the neutron is captured in such disintegrating collisions, or whether it merely passes through the nucleus on which it has such a catastrophic effect.

Mme. Curie-Joliot and M. Joliot and Dee have independently noted that some swift electron tracks are observed in the expansion chamber. The exact origin and nature of these particles will require careful examination. It is possible that a gamma-radiation is emitted from beryllium as well as the neutron. Mme. Curie-Joliot and M. Joliot found that the radiation from boron bombarded by alpha-particles behaved similarly to that from beryllium. It is possible that other elements will also give rise to radiations of this kind.

Whatever may be the final explanation of the interesting facts observed, it is clear that if they are due to a quantum of radiation, we must relinquish the laws of the conservation of energy and of momentum in the production of this radiation and its interaction with matter. If we wish to retain these laws, the neutron hypothesis seems the only alternative. In any case it is evident that these new discoveries have opened up a new region of research which is of great interest and promise.

THE MASTER KEY OF SCIENCE

REVEALING THE UNIVERSE THROUGH THE SPECTROSCOPE[1]

By HENRY NORRIS RUSSELL
PROFESSOR OF ASTRONOMY, PRINCETON UNIVERSITY

The great French philosopher of the last century, Auguste Comte, was an exceedingly well-informed and versatile man, but it was he who once remarked: "There are some things of which the human race must forever remain in ignorance; for example, the chemical composition of the heavenly bodies." To Comte and the other intelligent men of his time, this problem seemed hopelessly insoluble; there was no way of attacking it.

Of course this statement sounds ridiculous to us now. It became ridiculous because man's dream came true of a master key that would unlock many doors, one after another, and so open up many new realms of knowledge.

That master key was the spectroscope. No sooner was it discovered than the composition of the heavenly bodies, previously unknowable, became an open book. With its use, many of the familiar chemical elements were identified in the sun, and not long after, in the stars. Later work has extended the number of elements identified in the sun to sixty, and spectroscopic study has shown that the atmosphere of Mars contains oxygen and water vapor, while that of Venus shows no signs of them.

All the stronger lines in the spectra of the sun and stars and a host of the weaker ones have been identified. It has been demonstrated that the same atoms are present on earth that are also present in the remotest nebulae, in the relatively cold tail of a comet, and in the intensely heated surface of a white star. By showing these things, the spectroscope has given the most impressive of all proofs of the unity of nature.

This achievement has been described in poetry, as it should be, by Edmund Clarence Stedman, in one of his more philosophical poems "Corda Concordia." The stanza in which this is done is such good science, as well as such good poetry, that I would like to quote it:

> White orbs like angels pass
> Before the triple glass,
> That men may scan the record of each flame,—
> Of spectral line and line
> The legendry divine,—
> Finding their mould the same, and aye the same,
> The atoms that we knew before
> Of which ourselves are made,—dust, and no more.

It is more than two hundred years since Newton, passing his beam of light in a darkened room through a prism, saw the rainbow-colored streak of light upon the wall as the rays of different color were refracted in different amount by the prism, and so was led to realize the composite nature of white light. Unfortunately, Newton took his light through a small round hole and he took it from the large round sun; consequently, even if the sun had been all one color, the image that he would have had thrown on the wall would have been like the image that he got when it came through a pinhole in the window shade. If only he had had the wit to set up a narrow slit so that the image would have been sharp and not round, the master key might have been discovered.

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[1] An address delivered at the inauguration of the spectroscopic laboratories of the Massachusetts Institute of Technology, February 25, 1932.

Just after the first half of the nineteenth century was over, Kirchhoff and Bunsen made that simple but fundamental mechanical change. Really this master key was found in a narrow slit—simply in letting your light into this prismatic instrument through a slit so narrow that you obtained a sharply defined image. As soon as that was done, as soon as they took the light through a narrow slit into their prism, with an eyepiece to look at it and a couple of other lenses to make the light go in parallel rays through the prism—the new doors were opened and the new worlds free to conquer.

The next necessary advancement was the development of a more delicate method of spectrum analysis. This came with Rowland, the great Johns Hopkins physicist in the nineties. He developed an engine for ruling diffraction gratings, the device that is used for breaking light up into its components. The best of Rowland's gratings are the joy, the envy and the despair of the investigators today—the joy of the man who has one, the envy of his colleagues, and the despair of the man who tries to make one as good. Rowland devoted years to the study of the solar spectrum and reported and recorded in it the position of 20,000 lines, each one carrying its own story of some substance in the sun. When Rowland was through his work, thirty-six of the chemical elements had been identified in the sun. Since that day, of course, a number more have been added because plates have been developed which are sensitive to the red end of the spectrum, and Rowland had no such plates available. Partly for that reason, and partly because some substances are now available of which Rowland could not get specimens, sixty chemical elements have now been identified in the sun—most of them with certainty.

In the stars, we can not observe such immense detail as we can in the sun, although the big spectroscopes that are now being attached to the great refractors such as the Mt. Wilson 100″ telescope give us an amazing amount of information, and dozens of different chemical elements have been definitely identified in the stars.

The minute shift in the position of the lines due to motions of approach or recession has enabled us to detect and measure the rotation of the sun and the planets, to prove that Saturn's rings are not solid, but composed of myriads of tiny satellites, and to get one of the most accurate determinations of the sun's distance. Applied to the stars, it has determined the sun's motion among them, the distances of hundreds of individual stars, and the average for thousands more; has revealed hundreds of double stars too close to be resolved by the telescope, and determined the masses and even the diameters of some of them; and has disclosed those amazingly rapid motions of the remote nebulae—some as high as 15,000 miles a second—which point the way to new conceptions of the nature, the past and the future of the material universe. Spectroscopic tests have shown that the nebulae are of two kinds, one consisting of masses of luminous gas; the others, giving light like stars, must themselves be great clusters of stars at gigantic distances.

If the spectroscope has thus proved so profitable to the astronomer, what has it accomplished for scientists in other fields? The chemist owes to spectroscopy the discovery of at least ten of the elements, some by optical methods, others more recently by the aid of x-rays. Among these is helium, which was detected in the sun and its nature as a light gas correctly interpreted more than twenty years before it was "run to earth."

The classical physicist finds in the spectroscopic data his most precise standards of length, and some of his more accurate methods of measurement.

My friend, Dr. Meggers, of the Bureau of Standards, and his associates have developed very practical spectroscopy recently. Suppose, for example, you have some fusible plugs that are used in our overhead sprinkler systems. They are made of a fusible alloy which will be greatly damaged if it has any more than the most minute quantity of iron in it. To find this out by chemical analysis is a slow and tedious process; but you can take one of these plugs and test it with the spectroscope, and if the strong lines of iron show up, you know there is iron there. Comparative tests with materials of different composition give you an idea of the safe limits. Thus, with the spectroscope you can test these alloys in a minute part of the time that chemical composition requires.

But it is in the realm of atomic physics that spectroscopy has played its greatest rôle. Fifty years ago, Lockyer, from a study of the spectra of electric arcs and sparks, and of the stars, concluded that, in the spark and in the hotter stars, ordinary atoms are decomposed into products which give different spectral lines. This bold generalization was fully justified forty years afterward, by the development of the theory of ionization.

About forty years ago, series of lines were detected in many of the simpler spectra, and found to be representable by formulae in which the "Rydberg constant," common to all spectra, appeared. Here was evidence of some uniform feature in the constitution of the different atoms. The Zeeman effect, according to which a spectral line emitted by a source placed in a strong magnetic field is split up into polarized components, again showed features common to different atoms, and suggesting the presence within them of moving electrical charges. The Bohr-Rutherford theory of atomic structure—with electrons in orbital motion around a nucleus—was based very largely on these spectroscopic data. It accounted at once for the typical spectral series of hydrogen, and accurately predicted other series in the infra-red and ultra-violet. With simple modifications, it explained the more complicated system of series in the spectra of the alkalies. The multiple character of the terms of the series was later interpreted as a result of the spin of the electron—thus increasing the "astronomical" resemblance of the atom-model; while the appearance of numerous terms in the more complex spectra was accounted for by differently quantized inclinations of the electron orbits. The complex multiplets of lines found in the spectra were thus fully explained. In its final form (due to Hund) this theory has been brilliantly successful in elucidating the structure of atoms and interpreting and even predicting the details of their spectra. Work in this field has been very active, and only the most complex spectra (rare earths and some heavy metals) and those of a few very rare elements remain to be deciphered.

In the case of molecules, changes in the states of oscillation and rotation of the nuclei, as well as in the electronic states, are possible, and the spectra are much more intricate, consisting of complex bands comprised of closely packed lines. Those of diatomic molecules are now well understood—with important gains in our knowledge of molecular structure and the nature of chemical "affinity,"—and the still more intricate polyatomic molecules show signs of yielding. Different isotopes of the same element, when present in compounds, often give widely separated bands. From these, new isotopes of oxygen, nitrogen and carbon have been discovered, and the ratio of the masses of the different atoms determined with extreme precision. In atomic spectra, the isotope effect is extremely small, except for hydrogen—where it has recently permitted the identification of an isotope of double weight.

Fine-structure in the lines of heavier

atoms arises partly from the presence of isotopes, partly from some sort of "spin" within the atomic nucleus, and its study affords a promising approach to the problem of nuclear structure.

While all this was going on, x-rays were also found to contain monochromatic radiations, observable by using the atoms in a crystal as a diffraction grating. These spectra have given us information about the interior of atoms, comparable with that which optical spectra furnish concerning the exterior. They are much simpler than the latter, and now furnish the chemist with his most delicate test for the detection of new elements. Incidentally, they make it certain that except for the few well-recognized gaps, no elements lighter than uranium remain to be discovered.

Working in the opposite direction, x-ray spectroscopy opens the door to another untrodden realm—the exact study of the arrangement of atoms in crystals, which can now be specified in minute detail.

All through these triumphs ran a discordant note. Certain numerical relations—notably in the Zeeman effect—though exact, differed systematically from those predicted by the orbit theory, and every calculation based on the relative positions of electrons in these orbits led to a wrong answer. This discrepancy has vanished since the orbital picture of the atom was replaced by the difficultly visualizable wave-mechanics or the wholly unpicturable matrix-theory. When a modern lecturer tries to draw an atom on the blackboard, he uses no chalk, but an eraser, and constructs a smudge illustrating the relative probability of finding a unit-charge in different regions. But as a means of calculation—interpreting and, on occasion, predicting, the results of precise observation, the new theory advances from conquest to conquest.

The ramifications of these new ideas throughout the range of molecular and atomic physics are too numerous to mention. To take but one instance at random, the magnetic susceptibilities of solutions of salts of the rare earths may be fully explained by the theory of spectral structure—even though the spectra of the trebly ionized atoms (upon which these depend) have not yet been observed.

There is probably no field in which the new spectroscopy has been of more aid than in astrophysics. The recognition that Lockyer's enhanced lines are produced by ionized atoms, and the general application of the laws of ionization to stellar atmospheres have transformed our whole view-point. We know now that the disappearance of the lines of the metals from the hot stars means only that they have been so highly ionized that they no longer give lines in the observable region, and that the lines of the permanent gases, and the non-metals generally, are weak or absent in the cooler stars because their atoms are not highly enough excited to be able to absorb the observable lines. From measures of line-width, and also by study of multiplets, the actual number of atoms which produce a given spectral line may be estimated, and an approximate quantitative analysis made of the atmospheres of the sun and stars. The results indicate a remarkable similarity of composition, despite the great differences in the spectra of hot and cool stars. The relative abundance of the elements is similar to that in the earth's crust or in meteorites, with one noteworthy exception. Hydrogen—a minor constituent here—is overwhelmingly predominant in the stars. (The excess very likely escaped during the formation of our planet.) Both the temperature and pressure of a star's atmosphere may be found from the intensities of the spectral lines. The former agree with the values deduced from the colors of star-light; the latter are surprisingly small, and indicate that the atmospheres are of exceedingly low density. The whole atmosphere of the sun, brought to standard temperature and pressure, would make a layer of gas less than a hundred feet thick, of which the metallic vapors form about one per cent.

A similar conclusion was reached more than forty years ago by Lockyer, by the simple process of comparing the sodium lines in the solar spectrum with those absorbed by the vapor present in a Bunsen flame. The sun's atmosphere, of course, is not sharply bounded at the bottom; it grows hazier owing to the increasing density of the free electrons and ions, and passes into the luminous photosphere. The principles upon which this increasing opacity can be calculated are essentially spectroscopic, and the data regarding the ionization and excitation potentials of atoms, which it requires, have been derived spectroscopically.

Two more applications may be mentioned—to matter in extreme states of condensation and rarefaction.

From the spectroscopic data regarding atoms it follows that, at very high temperatures, inside the stars, they will be completely ionized down to bare nuclei and electrons. Matter in this state should be exceedingly compressible, but not infinitely so—the limiting factor being the degeneracy of the gas (in the sense of the new quantum theory) at a density several hundred thousand times that of water. The problematical white dwarf stars, like the companion of Sirius, show conclusive evidence of being in this state, while the shift towards the red of the lines in their spectra (coming from the outer atmosphere) affords an important confirmation of general relativity. At the other extreme, the gaseous nebulae—which from gravitational considerations must be of extreme tenuity—show spectral lines which were long a tantalizing problem. Modern spectroscopy revealed the existence of metastable atomic states, from which light-producing transitions would not occur unless the individual atoms were left undisturbed much longer than they would be except in an exceedingly rarefied gas. Bowen thus identified the nebular lines as "forbidden" lines of the sort produced by the most familiar elements, oxygen and nitrogen above all. The hypothetical unknown element nebulium thus very literally vanished into thin air.

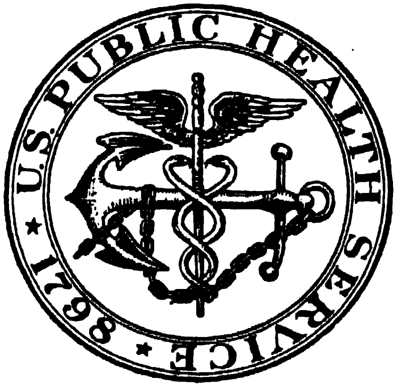
THE CADUCEUS

By STUART L. TYSON, D.D. (OXON.)

PELHAM MANOR, N. Y.

In view of the evident pride of our physicians in the emblem of their profession, as manifested, *e.g.*, on motor cars, on seals, charters, façades of medical buildings, hospital *stoai*, etc., it is curious to note how many there are who reveal, in the manifold expressions of their sentiment, an entirely erroneous conception of what in fact is the emblem of the healing art.

Ask the average *medicus* to describe the *signum* of Asklepios, the god of medicine; he will be almost certain to reply that it consists essentially of a *Caduceus*, *i.e.*, a wand with two serpents intertwined. Should the *advocatus diaboli* express doubt as to the correctness of the answer, he will perhaps be confronted with the *sigillum* of the U. S. Public Health Service, the insignia of the U. S. Army Medical Corps, the seals of not a few county medical societies, adornments on many buildings consecrated to the profession, such as the splendid "Medical Chambers" recently completed at 140 East 54th Street, New York; on hospitals (including that of the newest *Asclepieion* at New Haven, the University Health Department Building), etc., all of which exhibit the two snakes around the wand or forked rod. If the *paganus* be still skeptical, he may be referred to that fine book, "Devils, Drugs, and Doctors," by Dr. H. W. Haggard, associate professor of applied physiology at Yale, where on p. 15 f. (1st ed., 1929) it is noted that "the symbol of Aesculapius, the Caduceus—the two snakes twined on a staff—has survived, and is still used to-day as a medical emblem." Or he may even be shown the words of that prince of physicians, Sir William Osler, who, in his Silliman Lectures at Yale in 1913 on "The Evolution of Modern Medicine," the proofs of which were never wholly revised by the author,[1] seems (but only seems: for while the statement is unfortunately accurate for many groups in the U. S., with the notable exception of the A. M. A. since 1912,[2] the entire context, both photographic and verbal, negates the assumption) to lend countenance to the error. "Asklepios . . . remains our patron saint, our emblematic god of healing, whose figure with the *serpents* [italics mine] appears in our seals and charters" (p. 43). In the past six months the present writer has questioned thirty-one physicians as to the emblem of the healing god and in twenty-seven instances has received as



SEAL OF THE U. S. PUBLIC HEALTH SERVICE.

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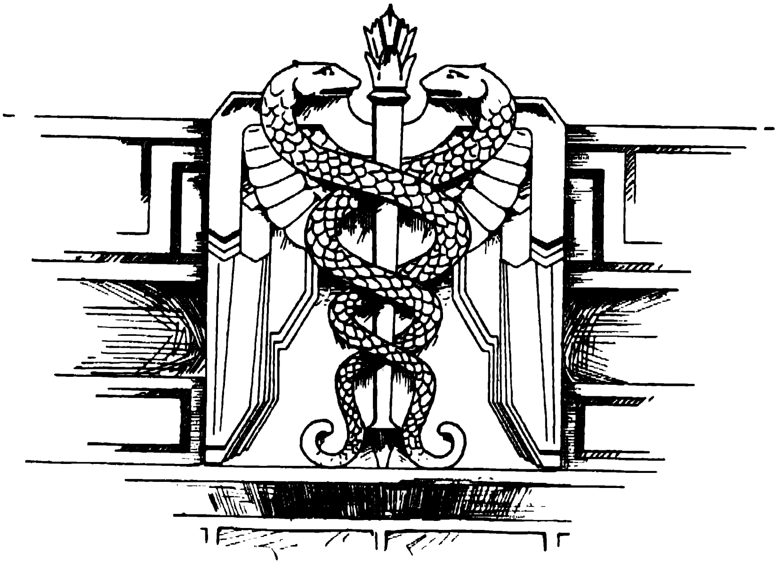
[1] *Cf.* Dr. Harvey Cushing, "Life of Sir Wm. Osler," Vol. II, pp. 292, 377, 385, 436: also "Annals of Medical History," Vol. IV, p. 214.

[2] "For a time the Caduceus was used as an emblem by the American Medical Association, but in 1912, after considerable discussion, the official emblem embodying the Aesculapian rod was adopted and is still in use." B. S. Engle, *The Classical Journal*, Vol. XXV, p. 206.



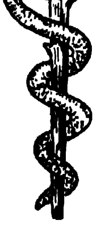
FAÇADE OF MEDICAL CHAMBERS, NEW YORK, SHOWING CADUCEUS.

de fide the reply that the wand with *two* snakes constitutes his *symbolum.*

It would ill become a mere layman to rail at these Asklepiads; but a professional student of the history of his art might well be tempted, on recalling the answers of his twenty-seven fellow-practitioners, to breathe the pious prayer of Thersites in "Troilus and Cressida":

> O thou great thunder-darter of Olympus! forget that thou art Jove, the king of Gods; and, Mercury, lose all the serpentine craft of thy Caduceus, if ye take not that little, little, less-than-little wit from them that they have!

For it is an incontrovertible fact that the wand with the two serpents is the symbol, not of Asklepios, but of Hermes (*Lat.* Mercury), of whose connection with the healing art there not only exists scarcely a chemical trace, but most of whose positive attributes are wholly alien to the noble profession of medicine; while on the other hand, the heavy staff or club, bearing a single twined snake, from the early days of Greek mythology until at least the period of Henry VIII, has invariably been associated with him whom all physicians of the Western world revere, not only as the very *Deus Medicinae,* but also as the fabled ancestor of Hippocrates, the true *Pater Medicinae.*



TRUE AESCULAPIAN SYMBOL, AS EMPLOYED BY THE A.M.A.

Let us first examine the term "Caduceus"—or probably more accurately "Caduceum."[3] It is the Latin adaptation of the Doric καρύκειον, or Æolic καρύκιον, rather than of the Attic form κηρύκειον, (the ρ becoming d, as ad = αρ), "a herald's wand," derived from κῆρυξ, "a herald" or "ambassador," in turn evolved from κηρυσσεῖν, "to an-

[3] It is a curious fact that neither Cicero, Nepos, Livy nor Pliny happens to employ the nominative, and it is therefore difficult to determine the predominant gender in antiquity; but inasmuch as the term is practically a transliteration of the Greek neuter adjective, it would seem (as against English usage) to be etymologically a neuter.

nounce": the neuter adjectival substantive denoting the symbol of the official state messenger as he went out to treat of peace. In the Greek world it was originally a shepherd's crook,[4] a forked olive branch adorned at first with two fillets of wool, then with white ribbons, and later (a recrudescence, as will shortly be shown, of a far earlier Eastern tradition), with two snakes intertwined, *the* Caduceus *par excellence,* the magic wand of Hermes, the heavenly messenger of the gods. This last, according to the monumental Oxford Historical Dictionary, "is its earliest and proper sense in English."[5]

Next, as to Hermes or Mercury, the true bearer of the Caduceus.[6] He was the son of Zeus and Maia, as Asklepios was begotten by the healing god Apollo. A late myth, however, makes him half-brother of the god of medicine, whose daughter Hygeia he is said to have married. This is about the extent of his connection with the healing art, unless, indeed, the giving or withholding of sleep and the promotion of fertility be regarded as therapeutic. However, in Tanagra he was believed to have averted a pestilence,[7] an action common to more than one of the Olympiads. But inasmuch as the respective symbols of the two gods were superficially so similar, it was perhaps only natural, in the ebb and flow of classical studies, that from time to time they should become confounded. According to one myth, Hermes obtained the Caduceus as follows: With great ingenuity he had evolved the lyre from the shell of a tortoise, and playing thereon before the enchanted Apollo what may be presumed to have been the Greek prototype of the Fifth Symphony, received in return for the gift of the instrument to the spellbound god, an ambassadorial portfolio to mediate between the gods and men. Whereupon, as now high heaven's herald, he was given the magic forked wand, the *signum* of the peace-bringer, ultimately decorated with the two intertwined serpents, and sometimes also with wings, as symbolizing his incredible speed. Historically, the Caduceus, adorned with a male and female serpent intertwined, carries us back to a period far earlier than that with which we are at present concerned, and is definitely associated with the idea of fertility, which, as just stated, Hermes was believed to promote.[8] Greek and Roman myth supply several stories as to the *raison d'être* of the two snakes on Hermes' wand of office. Perhaps that related by Hyginus, in his "Poeticon As-

THE CADUCEUS, ERRONEOUSLY EMPLOYED BY MANY PHYSICIANS AS THE SYMBOL OF THEIR PROFESSION.

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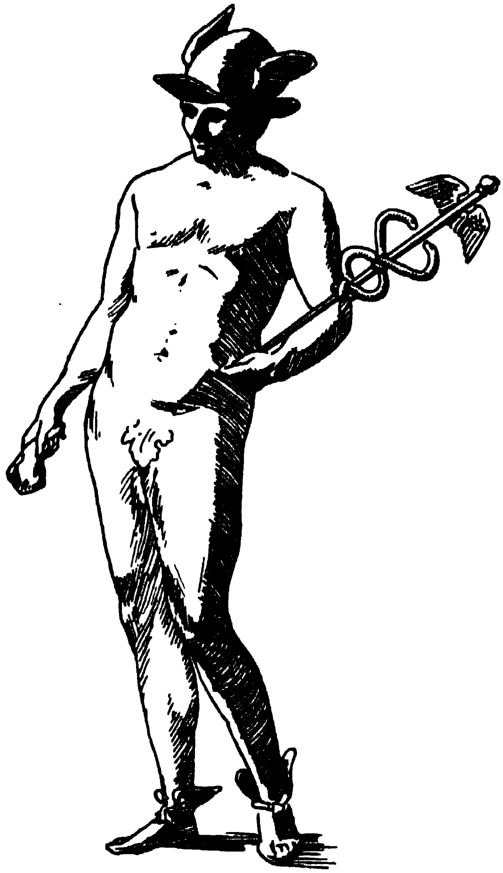
[4] Farnell, "Cults of the Greek States," Vol. V, p. 20.

[5] Thus Spenser, in 1591, referring to Mercury: "And in his hand
He took Caduceus, his snakie wand,
With which the damnéd ghosts he governeth,
And furies rules, and Tartare tempereth."

[6] Cf. Ovid, *Metam.*, 8, 627, who refers to him as "Caducifer." Facciolatus and Forcellinus, in their "Totius Latinitatis Lexicon," cite the following from an old inscription: "*Mercurius petasatus et caduceatus*"—"Mercury with his travelling cap on and equipped with the Caduceus."

[7] Paus. IX, 22, 1.

[8] For the Caduceus of this period, see the scholarly essay, "The Babylonian Origin of Hermes the snake-god, and of the Caduceus," by A. L. Frothingham, in the American Journal of Archaeology, 2nd Series, Vol. XX, p. 175 ff. "This proto-Hermes was always a snake-god. . . . But it is an essential element of his function that he was not a single snake . . . but the double snake, male and female, the most prolific form of copulation in the animal kingdom. For this reason the emblem of the god was the Kerykeion or Caduceus, a pair of snakes wound around a wand or sceptre."

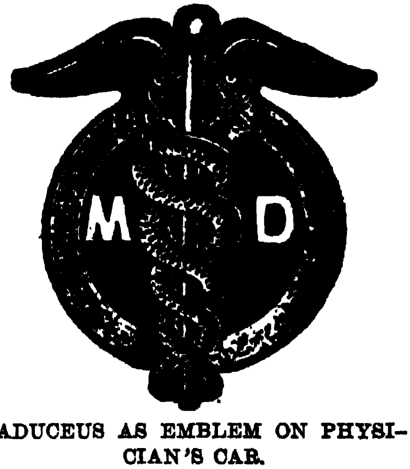


HERMES, WITH CADUCEUS AND WELL-FILLED PURSE. (ARLES).

tronomicon," will do as well as any other. "Mercury . . . saw two serpents entwined in mortal combat. Separating them with his wand, he thereby induced a state of mutual peace. As a result of this episode, the wand with two serpents intertwined came to be regarded as the sign of peace." Macrobius,[9] however, evidently recalling the earlier Oriental tradition, says that the two serpents were "*non dimicantes sed coeuntes . . . pressis osculis ambitum circuli jungunt*"!

How singularly inappropriate is the use of his emblem by physicians may be realized by recalling some of his functions. As god of the high-road and the market-place Hermes was perhaps above all else the patron of commerce and of the fat purse: as a corollary, he was the special protector of traveling salesmen. As spokesman for the gods, he not only brought peace on earth (occasionally even the peace of death),[10] but his silver-tongued eloquence could always make "the worse appear the better cause.[11] From this latter point of view, would not his symbol be suitable for certain Congressmen, all medical quacks, book agents and purveyors of vacuum cleaners, rather than for the straight-thinking, straight-speaking therapeutist? As conductor of the dead to their subterranean abode,[12] his emblem would seem more appropriate on a hearse than on a physician's car. And so one might go through the list. When but a new-born baby, for instance, he escaped from his cradle and stole the oxen of Apollo; exhibiting even at that tender age the sinister quality of his genes.

The following fair *florilegium*, culled from the "Homeric Hymn" to Hermes (Shelley's translation), illustrates a great unknown Greek's judgment of one



CADUCEUS AS EMBLEM ON PHYSICIAN'S CAR.

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[9] *Saturn.* C. 19 f.—cited by Facciolatus and Forcellinus *sub v.* "*Caduceus.*"

[10] *Cf.* his murder of Argus: Apollod. II, 1, 3.

[11] "As an adroit speaker, he was especially employed as messenger, when eloquence was required to attain the desired object." L. Schmitz, D.G.R.B.M., II, p. 412.

[12] Od. XXIV, 1, ff.

whose emblem so many of our medical men still employ. The good god himself meekly confesses that "I am the king of robbers." Apollo cries:

I fear thee and thy chameleon spirit. . . .
Thieves love and worship thee—it is thy merit
To make all mortal business ebb and flow by "roguery";

and he prophesies that

This among the gods shall be your gift—
To be considered as the Lord of those
Who swindle, house-break, sheep-steal and shop-lift.
A schemer subtle beyond all belief.
I never saw his like either in heaven or upon earth for knavery or craft.

To crown his character, he was a murderer.[13] Perhaps one of his most amiable characteristics, apart from his proclamations of "peace, peace" (occasionally when there was no peace), and his devotion to athletics, was his patronage of the ancient and honorable pastime of craps, over which, in the Greek world, he seems to have presided with relative impartiality. But in whatever capacity, good or bad, he is exhibited with his two serpents, his relationship to medicine is tolerably near absolute zero.

Far otherwise is the case with Asklepios, the divine healer, invariably depicted with the single snake, either coiled round his knotted staff, by his side, or being fed by his daughter Hygeia, and whose whole "life" was selflessly devoted to the amelioration of human suffering. He conducted no souls into the underworld. On the contrary, he was ultimately electrocuted by Zeus on complaint of Pluto, who averred that by his supernatural medical skill he was depopulating hell and so reversing the whole cosmic order! Nevertheless, so great was his celestial fame that, by way of compensation, he was forthwith translated into heaven as a constellation, "The Serpent-Holder."[14] It appears superfluous to say that he was never pictured in Greek or Graeco-Roman art as bearing the Caduceus, an emblem utterly foreign to him, and with which at no time had he either direct or indirect connection. The very term itself, as wholly devoid of any medical connotation whatsoever, has no place in the Aesculapian vocabulary.

Who he really was—whether god or man—is immaterial to our purpose. Classical students will realize that here as elsewhere in this brief paper, no more than the baldest selection, out of the many and variant myths, has been attempted. It is hoped, however, that the outstanding attributes of the respective gods have been fairly adumbrated. Whether, as many scholars believe, he was originally no more than a Thessalian warrior who "turned" to medicine —as in the Iliad, where he is merely "the blameless physician"—he early became a chthonic snake-god. Sir James Frazer, in his extended note on Pausanias II, 10, expresses his own judgment as follows. "It is tolerably certain that originally Aesculapius was neither more nor less than a serpent, which at a later time was transformed into an anthropomorphic god, with a serpent symbol. . . . The ancients explained the connection of the serpent with Aesculapius by saying that it is the natural symbol of the healing art, since it periodically renews itself by sloughing off its old skin." So in his note on "The Fasti" of Ovid (Vol. 2, p. 132): "It was natural to suppose that a creature which could thus renovate itself could also renew the energies and prolong the life of the sick and suffering. . . . So firmly implanted in the minds of the ancients was this association of the renewal of youth with the sloughing of the skin that both in Greek and Latin the ordinary word for old age was also applied to the slough of serpents." There is perhaps little doubt that the whole matter, in its ultimate analysis, is to be referred to phallic worship, with the serpent itself as phallos. But to follow this up would carry us too far afield.

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[13] Apollod. *loc. cit.*

[14] Sir T. Clifford Allbutt, "Greek Medicine in Rome," p. 46.

While the origin of the term "Asklepios" is uncertain, there is some probability that it was derived from a Greek word meaning "the creeper," *i.e.*, one who walks by rolling round and round,[15] again suggesting the snake. He is represented in ancient art as a reverend bearded god,[16] leaning heavily upon a thick knotted staff, around which a serpent is coiled; or sometimes seated, while votive offerings are brought to him, with the serpent by his side. In this latter connection, every one will recall the last poignant words of Socrates when, after drinking the hemlock in his prison and "already growing cold about the groin," "he uncovered his face and spoke for the last time. 'Crito,' he said, 'I owe a cock to Asklepios: do not forget to pay it.' 'It shall be done,' said Crito . . . " and thus died one "who was the wisest and justest, and the best man that I have ever known."[17]

From Epidauros, the splendid seat of his chief healing shrine, Asklepios as a snake came to Athens in 420 B. C., and to Rome in 291, which latter event ultimately gave to the Western world the more familiar Latin equivalent "Aesculapius," the progressive evolution of the term being somewhat as follows:

> (1) Aisclapius, (2) Aeselapius, (3) Aisculapius,[18] (4) Aesculapius (*Cf.* the older Epidaurian form Ἀισκλαπιός, and the Thessalian Ἀσκαλαπιός.

AESCULAPIUS. (NAPLES MUSEUM).

Following the ravages of the pestilence at Rome in 293, an embassy was dispatched to Epidauros to secure the services of the god, who in the form of a snake was at length brought in great state by ship up the Tiber;[19] and himself sliding overboard and selecting the *Insula Tiberina* as his home, was forthwith received into the Pantheon, "the first instance of the Romans having adopted a cult from the Greek mother-country." According to Professor Thrämer, of Strassburg, from whose work[20] the above citation is taken, there were no less than 410 localities connected with his cult, testifying at once to the enormous expansion of the popular belief in the powers of "the Beloved Physician," and to the fact that "the serpent is the perpetual symbol of Aesculapius."[21]

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[15] Allbutt, *op. cit.*, p. 46.

[16] J. Harrison, "Prolegomena to the Study of Greek Religion," p. 340 f. "We conceive of Asklepios as he is figured in many a Greek and Graeco-Roman statue, a reverend bearded god, somewhat of the type of Zeus, but characterized by the staff on which he leans and about which is twined a snake. The snake . . . is the symbol of the healing art, and hence the attribute of Asklepios, god of medicine."

[17] Phaedo, LXVI.

[18] So spelt at *Insula Tiberina*.

[19] *Cf.* Livy, *Epit*, XI.

[20] Encl. R. E. VI, pp. 550, 554.

How, then did his symbol become confused with that of Hermes: a phenomenon, so far as I know, confined to-day entirely to the United States? According to Engle,[22] the earliest instance of the confusion is that of the famous Swiss medical printer, Johann Froben (1460–1527), who, evidently familiar with Hermes' Caduceus and also with the New Testament, pictured in his publications a two-serpented wand, surmounted, not by wings but by doves: and over all, as obviously excellent advice for physicians, the Greek original of the saying of Christ, "Be ye wise as serpents and harmless as doves." But in reality there appears no reason to believe he intended his device as the symbol of either Aesculapius or Hermes. On the contrary, it would seem quite clear, from the plural number both of serpents and doves, taken with the words of the overarching motto, that he had constructed his own symbolism for the emblem. However this may be, his fame appears in some measure to have set a precedent; for Sir William Butts, physisian to Henry VIII, employed the erroneous *signum;* and a few years later Dr. John Caius presented to Gonville and Caius College, Cambridge, a silver Caduceus, as to the significance of which he wrote his own Latin interpretation.[23]

We do not hear of it again until 1844, when it appears on the title-pages of the medical publisher J. S. M. Churchill, of London; and so far as the present writer is aware, this is the last that is heard of it in England; for the true Aesculapian emblem is used to-day by the Royal Army Medical Corps, and also by the French Medical Military Service. But in 1856 the two snakes once more re-appear, this time on the chevrons of hospital stewards of the U. S. Army; later, on the seal of the U. S. Public Health Service, and in 1902 on the uniforms of the U. S. Army medical officers. From these sources, apparently, the erroneous symbol[24] extended over nearly the whole of the American medical profession, large numbers of which still believe that what in reality is the emblem of the god of thieves[25] is that of the immortal healer, "the blameless physician" of the Iliad.

As one recalls the cumulative accomplishments of their respective disciples throughout the ages, from the primitive *incubatio* of Epidauros to the triumphs of modern preventive medicine on the one hand, and from the petty thievery of Hellas to the highly organized banditry of to-day on the other; to the follower, whether of Asklepios or of Hermes, it might significantly be said in the 20th century, as in the 18th, the epitaph over the door of St. Paul's Cathedral reminded those who desired a magnificent mausoleum for the great architect of the famous edifice, *"Si monumentum requiris, circumspice!"*

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[21] Schmitz, *Op. cit.* Vol. I, p. 45.

[22] *Op. cit.*, p. 207. *Cf.* also "Annals of Medical History," Vol. IV, p. 301 *ff.*

[23] For its text, *Cf.* Classical Journal, Vol. XXV, p. 207.

[24] The contention that the originators of its use in the Army Medical Corps were fully aware it was the symbol of Hermes, and did not intend this non-medical emblem which they placed on the collars of medical officers to have any medical significance whatever, is at once true and irrelevant. Because (without entering upon the symbolism which they attached to it), it was well nigh inevitable, in spite of all hypothetical disclaimers, that the Caduceus, superficially so similar to the Aesculapian staff, and now employed by "Government medical officers," should soon come to be generally regarded "as a symbol of the medical profession" in general (Dorland, "The American Illustrated Medical Dictionary," latest edition, *s.v.* "Caduceus"); and thereupon, by easy stages, to be widely accepted as the emblem of Aesculapius himself. And this is exactly what appears to have happened.

[25] "The patron-god of thieves, liars and defrauders." Farnell, *op. cit.*, V, p. 23.

TIME-CHANGES OF THE EARTH'S MAGNETIC FIELD[1]

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THERE is about the Earth a magnetic field. Its cause and origin are veiled in mystery as in the case of that other great natural phenomenon, gravitation. Unlike the latter, one can not immediately recognize the Earth's magnetism through any physical sense. An unexpected fall apprises one of the existence of gravitation, but no bodily effect is noticed in the Earth's magnetic field, although it is real as that of gravity and is subject to relatively greater local anomalies than the gravimetric field.

The familiar compass-needle demonstrates that magnetic forces are present everywhere in the Earth. Ocular evidence of this force may also be obtained by its inductive magnetic action upon a material highly susceptible to such action, for example, an alloy with unusually great capacity for transient induced magnetization in weak magnetic fields such as that of our planet. Permalloy has been developed in recent years to supply the need of such a material to improve cable communication. When a thin long rod of permalloy is directed toward the north magnetic pole of the Earth's field, the magnetization induced in the bar because of that field is quite sufficient to lift small pieces of permalloy. But as the rod is turned with its length at right-angles to the field and thus in the direction least favorable to induction, it loses the magnetism induced by the Earth and will no longer support such metal strips, which fall.

The picture of magnetic phenomena is incomplete if viewed only in a man-made laboratory, even though we can now produce there an artificial magnetic field within a space of a cubic inch which is about 100,000 times more intense than that of the Earth. Fortunately, Nature provides not only the Earth and its atmosphere as a great magnetic laboratory but also continuously performs experiments, utilizing as apparatus the Sun, the Moon and radiations from space. It is, however, only within historic times that we have appreciated the opportunity of putting this great laboratory to human use.

The discovery of the lodestone with its mystical power of attracting particles made of iron paved the way to the development of the magnetic compass, which has been in use by navigators since the eleventh century. This magnetic property of the lodestone—the "leading stone" of the Scandinavians, the "loving stone" of the French—was known to the Greeks according to authentic records some time about the end of the seventh century B. C. Various traditions ascribe such knowledge also to the Chinese as much as 2,600 years before the Christian era, and to the Japanese during the second half of the seventh century, but there is some question as to their authenticity.

In attempting to solve the mystery of the lodestone it was discovered that, when mounted in a block of wood and floated in water, one direction would always be indicated, that is, magnetic north and south. This was followed by

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[1] The first in a series of three lectures concerning the magnetic field of the Earth and its atmosphere, delivered at the Carnegie Institution of Washington, on March 8, 1932.

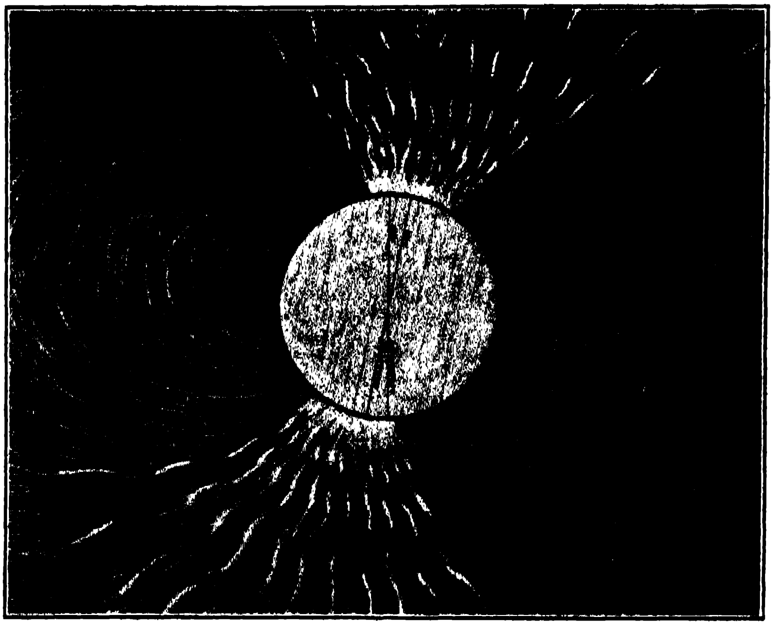


FIG. 1. THE MAGNETIC FIELD ABOUT THE EARTH

the first European treatise on the magnet written about 1269.

That property of the magnetic field of the Earth giving direction to the compass-needle was thus utilized some centuries before Columbus began his voyages to the western hemisphere. He, however, was the first to determine that the compass did not point true north except in certain places. We all know the story of the threatened mutiny on his first transatlantic voyage when the crew saw the compass pointed 10° west of true north instead of north as indicated by the pole-star, and how apparently he shifted the compass-card on its needle during the following night, thus quieting the fears of his men and inducing them to continue. But even to-day there are many who think of the compass-needle as showing direction "true to the pole of the heavens or the polar star."

Magnetic dip or inclination was unknown until 1576, when Robert Norman, a practical seaman and instrument-maker, published "A newe discovered secret and subtill propertie concernying the declinying of the Needle, touched therewith under the plaine of the Horizon." His discovery that the magnetic needle, when mounted on a horizontal axle so as to be free to move in the vertical plane, dipped below the horizon, gave the first hint that the source of the magnetic field of the Earth might be within the globe and not in the stars as previously supposed. It was not until 1600, however, that William Gilbert published his famous volume in which he pointed out that the Earth itself acts to a certain extent as though it were a great spherical magnet. Gilbert's conclusion thus preceded Newton's announcement of universal gravitation. Taken as a whole, the Earth is a feeble magnet. It is possible to magnetize our modern hard steel ten-thousand fold as much. Even so, since the globe is large, its total magnetism is equivalent in effect to eight hundred quintillion one-pound magnets of our best magnet-steel, could they be placed at its center.

The Earth is not uniformly magnetized and the principal magnetic poles are distant 1,200 miles or more from its geographic poles. The north magnetic pole, first visited a century ago June, 1931, by Ross and again in 1903, by Amundsen, is on Boothia Peninsula in northern Canada. The south magnetic pole, in South Victoria Land, has not yet been visited. Thus the magnetic poles are not diametrically opposite each other, the line joining them passing some 750 miles away from the center of the Earth.

The magnetic field extends far out into space. Four thousand miles above the Earth's surface it is still one eighth as great as at the surface. One may picture it as made of innumerable lines of magnetic force or action closely packed as schematically shown in Fig. 1. These lines of force are parallel to the surface near the plane of the equator, but as they approach the magnetic poles they bend and converge. Minute electrified particles in varying numbers are coming continually from the Sun. Once within the Earth's magnetic field, these particles or corpuscles are entrapped by the outermost lines of magnetic force and travel in paths around them. They get deeper down in our atmosphere in the polar regions, where the magnetic-force lines are steepest. When the electrified particles pass through the atmosphere they cause the air to glow by their impact, causing the brilliant polar-light displays sometimes seen in the northern and southern sky. From simultaneous photographs of aurora, taken at two stations a known distance apart, it has been found that polar-light beams generally do not come closer to the Earth's surface than about 50 miles; some come no closer than 300 miles or more.

The Earth's outer crust or shell, some 50 or more miles thick, is not homogeneous and therefore is not uniform in its magnetic behavior. Thus there are many regions of local magnetic disturbance, such as are caused by magnetic ore-deposits, some so great as to give rise to local poles and other irregularities in the general magnetic field.

The study of the character and behavior of this field therefore calls for observations not only on the surface of our globe but also in its interior and in its atmosphere. This applies particularly to the higher atmospheric limits and to the Earth's enveloping skin

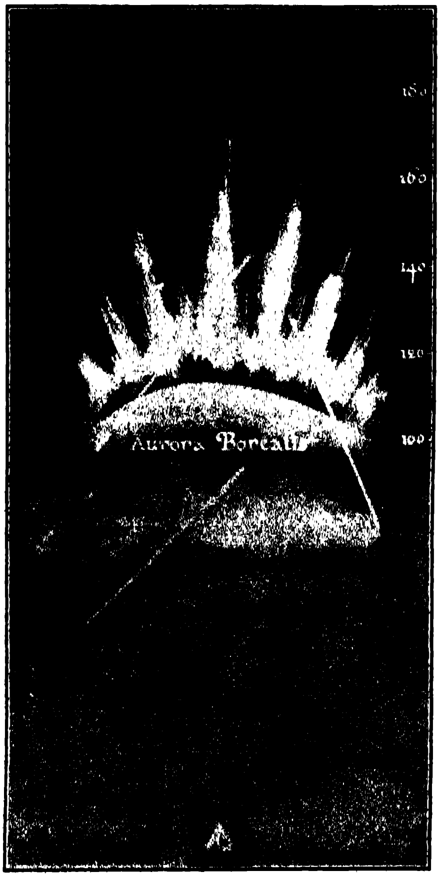


FIG. 1A. THE HEIGHTS OF VARIOUS PHENOMENA IN THE ATMOSPHERE (AFTER DOBSON)

or crust, where we apparently must look for explanations of those constantly occurring regular and irregular variations with time of the magnetic field which are the subject of this paper.

That our magnetic field is subject to progressive change or secular variation, that is, a slow age-long variation, was first noted by Gellibrand in 1634. In a book published in London (June 12, 1634) entitled "A Discourse Mathematical on the Variation of the Magnetical Needle Together with its Admirable Diminution Lately Discovered" he announced for the first time that "Variation is accompanied with a variation." Besides the secular variation, other more or less regular time-changes include daily inequalities, taking place chiefly during daylight hours and varying in magnitude and character with geographic position, with the seasons of the year, and with disturbances on the Sun. There are also short-period, long-period and sudden-commencement disturbances, commonly designated magnetic storms, apparently accompanying solar disturbance and other cosmical phenomena.

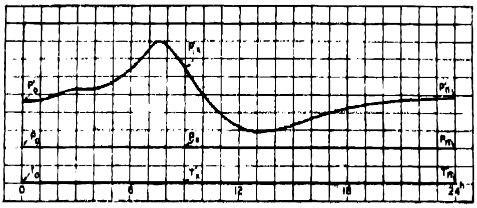


FIG. 2. GRAPH OF DATA VARYING WITH TIME

Much of what is known concerning time-changes can best be visualized graphically. Many of the photographic records upon which conclusions are based are in effect motion pictures of the experiments constantly being performed by Nature in her great laboratory. It is therefore desirable to give first some explanation of one method in common use to represent any quantity which varies with the passing of time or with some other variable. Consider, for example, any period over which a certain quantity is observed. It may be for centuries, for years, for months, for days, for minutes or for any other period represented by a straight reference-line as the one from T_0 to T_n in Fig. 2. That line may be

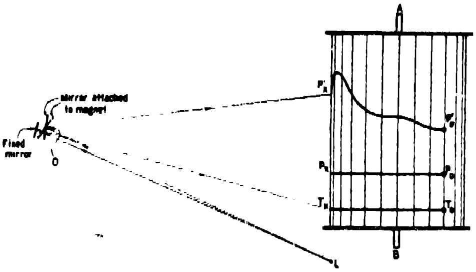


FIG. 3. SCHEMATIC DIAGRAM SHOWING PRINCIPLE OF RECORDING MAGNETIC VARIATIONS

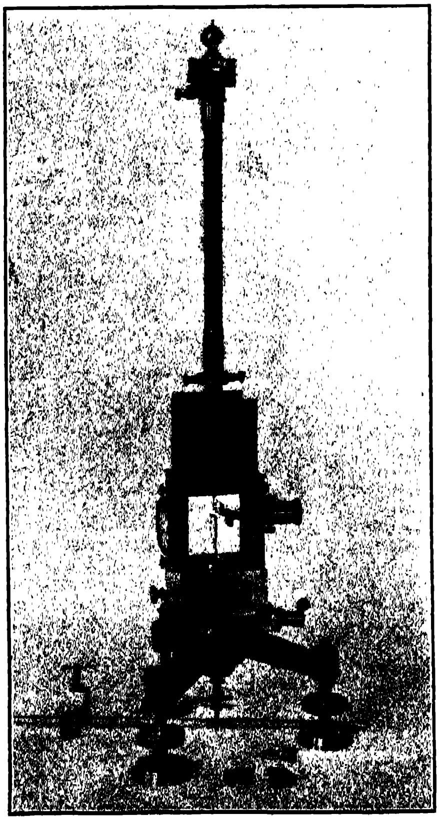


FIG. 4. MAGNETIC VARIOMETER

AS USED FOR RECORDING CHANGES IN COMPASS-DIRECTION divided into a number of equal parts each corresponding to the selected time-unit, for example, in hours, in which case T_0 represents 0^h or midnight of the day and T_n the following midnight. Each hour is then represented at successive points 1/24, 2/24, 3/24, . . . of the length T_0T_n measured from T_0. On the lines at right-angles to this line at any of these points then may be plotted to any arbitrarily chosen scale the difference between this reference-line and the observed value at any time T_x. The phenomenon being one in which there is no change during the time represented, the graph representing it would be a straight line such as P_0P_n parallel to T_0T_n. For some phenomenon not constant during the time-interval being considered the line joining values plotted to our arbitrary scale on perpendiculars at the successive unit time-points to represent the changing values will form some regular or irregular curve such as P_0' P_x' P_n'. In an instrument to record change in compass-direction, consider Fig. 3 as a horizontal projection of a mirror attached to a magnetic needle, the latter so suspended at a point above the paper as to be free to rotate about its vertical axis at O. Suppose a source of light at L providing a horizontal light-beam directed toward the mirror; when the compass-direction changes through a small angle, the mirror rotates with it to some position as that shown by the heavy dotted line, and the reflection of the light-beam changes from OP_0' to OP_x'. A second mirror, fixed in position, causes a steady reflection of the light-beam to give a reference-line corresponding to T_0T_n. Now if a sheet of photographic paper, suitably protected from all light except the reflected beam, be so mounted as to have uniform motion either in the vertical plane or on a cylinder rotating on an axle AB, then as the compass-direction changes, the light-beam focused on the sensitive paper gives a photographic record as the paper shifts.

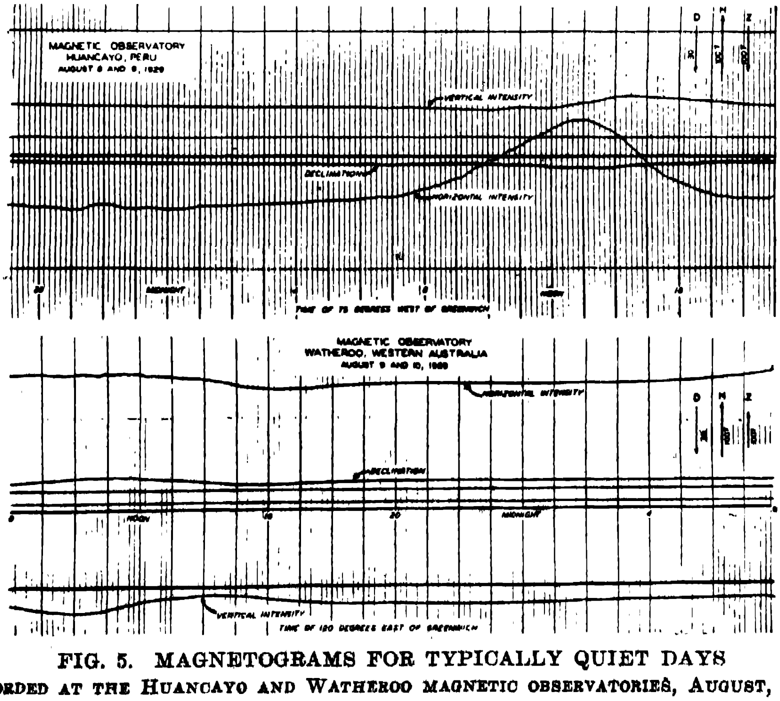


FIG. 5. MAGNETOGRAMS FOR TYPICALLY QUIET DAYS
RECORDED AT THE HUANCAYO AND WATHEROO MAGNETIC OBSERVATORIES, AUGUST, 1929

Upon developing this sensitized sheet we have a complete record of the movement of the compass-needle during the period. It is comparatively easy to determine by experiment or measurement of distances the length of the perpendicular to the reference-line of such a record for a unit angular motion as, for example, a single minute of arc or any other unit of measure. When such a method as outlined is translated into an actual instrument, as in Fig. 4, the optical and photographic recording devices intrinsically constitute substitutes for very long magnets which would be difficult to support so that they might swing freely with changes in the Earth's field. The length of the magnet in such a variometer is less than an inch, but with the optical arrangement this becomes theoretically infinitely long. Some actual photographic records of daily variations of the direction of the compass (magnetic declination) and of the forces acting in the vertical and horizontal planes are reproduced in Fig. 5.

SECULAR VARIATION

The usefulness for navigation at sea of magnetic direction or declination as indicated by the compass has stimulated and maintained interest in determining its value since the time of Columbus. Before the invention of chronometers it was thought that geographic position might be derived from knowledge of changes from place to place in magnetic declination and inclination. This led to the first systematic oceanic survey by the astronomer Edmund Halley in the Atlantic Ocean, during 1698–1700, on the sailing vessel *Paramour Pink*. As one result of his voyages the first isomagnetic chart was published. It showed lines at all points on which the compass-direction

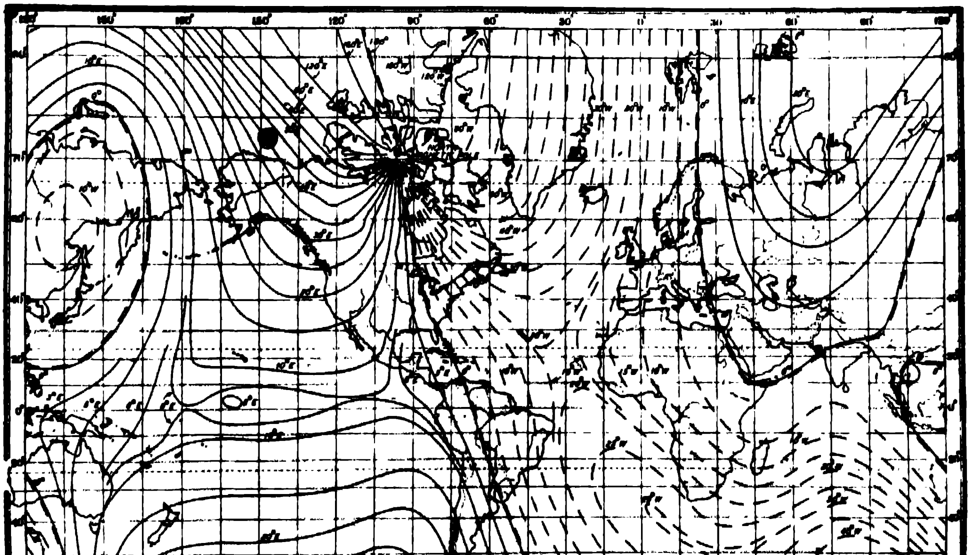


FIG. 6. CHART SHOWING LINES

ALONG WHICH MAGNETIC DIRECTION—DECLINATION—IS THE SAME FOR EPOCH 1930 BASED ON ISOGONIC CHART OF THE UNITED STATES HYDROGRAPHIC OFFICE

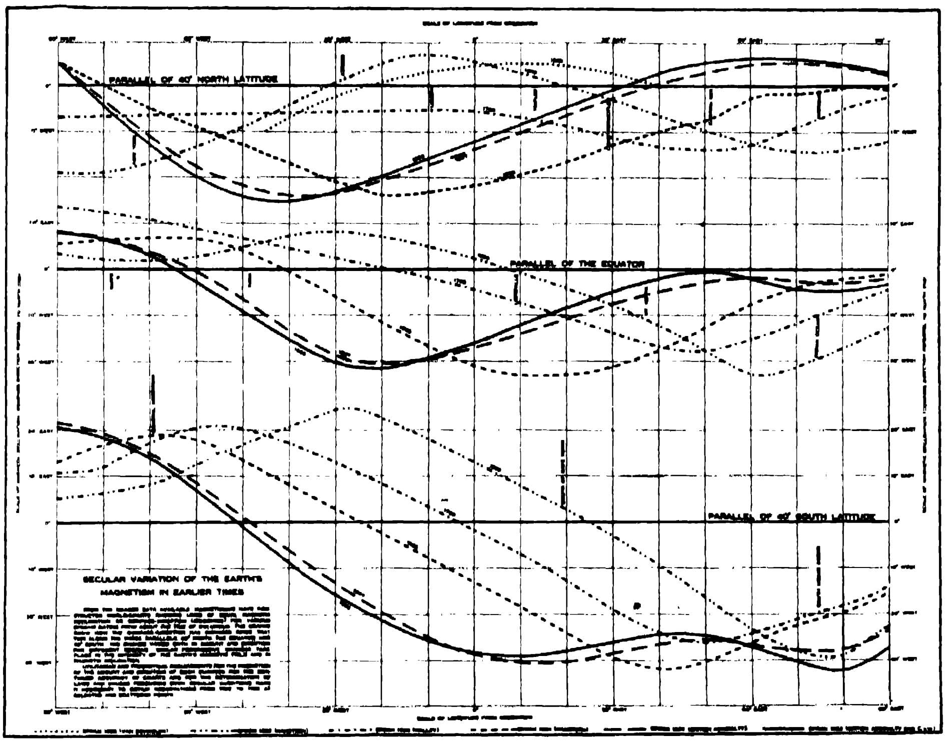


FIG. 7. GRAPHS SHOWING SECULAR VARIATION

IN DECLINATION OF THE EARTH'S MAGNETISM DURING 1500 TO 1922 FOR PARALLELS OF LATITUDE 40° NORTH, 0°, AND 40° SOUTH FOR LONGITUDES 90° WEST TO 90° EAST OF GREENWICH

differed from true north by the same angle, that is, lines of equal magnetic declination or isogonics. This chart and succeeding ones based on later data from time to time show the progressive changes in the position of these lines—changes known as secular variation. Fig. 6, for declination, is based on the latest isomagnetic chart published by the United States Hydrographic Office and applies for the epoch 1930. Its contrast with Halley's chart strikingly indicates the great accumulation of observed values during the past three centuries—an accumulation to which the Carnegie Institution has made large contributions since 1905 through its magnetic-survey operations on sea and land. The secular changes in the compass-direction in earlier times are indicated by Fig. 7, along several different parallels of latitude for various epochs.

Another picture of secular variation

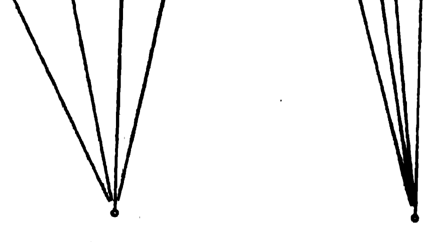


FIG. 8. SECULAR VARIATION OF COMPASS-DIRECTION AT LONDON AND AT BOSTON

utilizing observed compass-directions at London and at Boston is given by Fig. 8, showing the observed true bearing of the compass in different years. The importance of these changes in any practical use of the magnetic compass or needle may be realized by considering the observed data at London. There the magnetic needle pointed 11° east of north in 1580, changed gradually until it pointed 24° west of north in 1812, and since then has shifted eastward and now points only about 13° west of north. These results might be taken to indicate a complete cycle of change of about 500 years, but centuries more of observations are needed to verify such an indication.

For the purpose of illustration here, as well as later, let us conceive a thin, giant compass-needle about two miles long supported at its center by a pivot in which it is free to rotate, its north-seeking end taking at all times the direction of the Earth's magnetic field. The north end of this giant needle would move a little less than 100 feet for a change of one degree in direction or about one and one-half feet for a change of one minute of arc. At London its end would have moved westward from 1580 to 1812 more than 3,200 feet and then about 1,000 feet eastward to the present time. Here in Washington the annual change at present is such that the end of our giant needle would move because of it only about one-sixth of an inch per day toward the west, or a total of about five feet in the year. In the past 50 years this motion here would have totaled some 400 or 500 feet—a long city block—from the east.

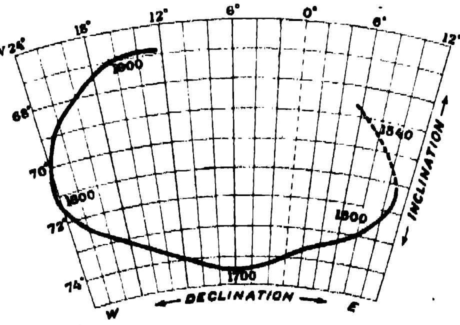


Fig. 9. Secular change in magnetic declination and inclination at London, 1540 to 1900 (after Bauer)

A more illuminating graphical method developed in an early paper by Bauer to represent observed data is illustrated in Fig. 9. In this the magnetic needle is considered as being supported at its center so as to be free to turn in any direction in space. The changing position of a needle so mounted would show by the motion of its end secular variations both in the horizontal and vertical planes. At London such a needle would have described a conical surface in a clockwise direction. However, similar graphs for other stations in various parts of the world show different periods and amplitudes of this motion in space. So we may not assume a cyclic secular-variation of common period applying to the whole Earth. We must, therefore, dismiss as insufficient the popular notion that changes in compass-direction arise wholly or mainly from a shift in the position of the magnetic axis or of the magnetic poles of the Earth.

There is another interesting possible method by which secular-variation information may be extended to times more remote than those for which observations exist. When lava cools and freezes following a volcanic outburst, it takes up a permanent magnetization dependent upon the orientation of the Earth's magnetic field at the time. This, because of small capacity for magnetization in the Earth's weak field after freezing, may remain practically constant. If this assumption be correct, the direction of the originally acquired permanent magnetization can be determined by laboratory tests providing every detail of orientation of the mass tested is carefully noted and marked when it is removed. Samples of lava-flows of known date from Mount Etna back to 1284 have yielded fairly consistent data for magnetic declination and inclination, which apparently indicate a secular-variation period of about 750 years. Similar measurements have been made using lava-flows caused by eruptions in the fourth century B. C.; however, results depending upon measurements of this kind must be used with caution. There is another possible source of such data, although certainly even more speculative than the lava-flows. When vessels made of clay containing iron compounds are fired, they take on and retain a permanent magnetic condition and axis-direction depending upon their orientation in the Earth's field at the time of firing. These are negligibly influenced by later changes in the Earth's field. Determination of direction of the magnetic axis may then give some idea of the inclination of the Earth's magnetic field at the time the vessel was made.

During the past quarter century marked progress has been made in accumulating accurate and coordinated information which is beginning to shed light on the character of the changes in the magnetic elements particularly in those regions controlled by the more advanced nations. Any attempt, however, to arrive at a solution by examining what takes place within a limited area or during too short an interval of time is not only a hopelessly inadequate undertaking but is very likely to lead to erroneous suppositions. It is but another instance of the danger of drawing conclusions from half-truths so aptly illustrated by the often-quoted dispute of the

> . . . six wise men of Industan to learning much inclined
> Who went to *see* the elephant though all of them were blind.

Like the subject of that classical investigation, this is also of mammoth proportions, and like those seekers for truth, investigators of magnetic changes have given clear and valuable reports of what has come within their observation, each of which is essential to the construction of the complete picture. But as vision improves with the gradual accumulation of details, the complex character of the subjects begins to become apparent, and some real progress toward a reconciliation of the differences in first impressions may now be expected.

As stated, the scattered observations of declination run back over 300 years in a few limited localities. The collection of observations of inclination, due of course to its smaller practical utility as well as to the greater difficulty attending its measurement, is much less abundant. It is now almost exactly 100 years since Gauss first described a method of obtaining the absolute measure of the magnetic intensity, or the strength of the magnetic field. It is really only since that time that serious research in secular variation —one of the most fascinating and at the same time the most suggestive of the time-change problems of the Earth's magnetism—has been possible. One hundred years would be scant time for the changes of the slow-moving forces to produce effects sufficient for the purpose even if a complete record of the changes for that period were at hand. But the record is fragmentary at best, so that what is known of secular variation prior to renewed activity in the study of the subject manifested by the establishment of a considerable number of permanent and well-equipped observatories during the closing years of the past and the opening years of the present century is in general limited to a few restricted regions or to scattered localities.

Whatever may be found to be the source of that magnetization, any changes affecting it must take into consideration the nature of simultaneous changes appearing over the entire surface of the planet. There is no known means of "remote control," no method by which in a carefully equipped observatory or comfortable laboratory in an agreeable climate surrounded by the

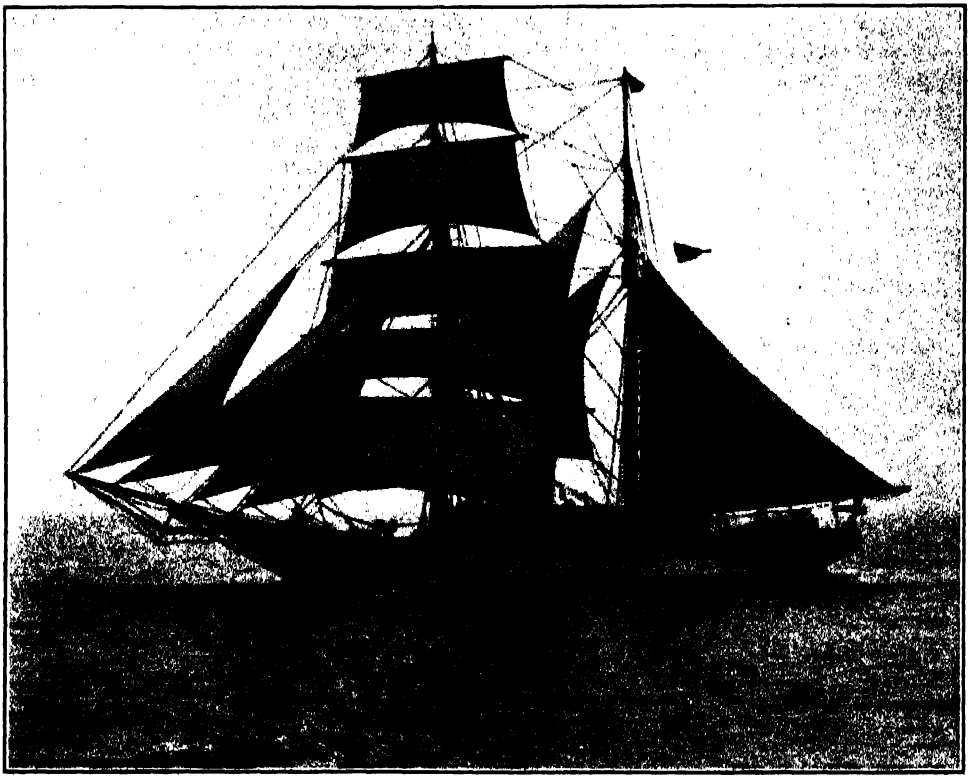


FIG. 10. NON-MAGNETIC VESSEL *CARNEGIE*, ELBE RIVER, JUNE, 1928

comforts of home, a competent staff of investigators can apply themselves to the solution of this problem. Only a portion of the land surface of the Earth is peopled by nations whose intellectual and material equipment enables them to maintain magnetic surveys, and of the entire surface of the Earth but a minor fraction is of land. There are the backward lands, the jungles, and the deserts; there are the remote and all but inaccessible islands of the great oceans, and great expanses of the sea where no land is; there is the far frigid north and the frozen unknown of the farther south; such places must be included in a complete and homogeneous network of stations if a satisfactory picture of what is taking place is to be drawn. Such places can not contribute the information of themselves; expeditions must be organized by others who are able to go and seek it—not once, but repeatedly—since it is not a condition, but the changeableness of a condition which is sought. The phenomenon is not static but dynamic; it is not a still picture which we visualize once for all but a moving picture requiring repeated exposures, and each exposure meaning a long and arduous journey to parts where means of travel are primitive or entirely lacking, where oftentimes expensive expeditions must be organized and financed to secure pictures in the setting desired.

Often when a place has been revisited after the interval of years it is impossible to find and make a redetermination at the same position as that previously used, and a new point must be chosen. But as the time-changes sought are relatively very small, and as local displacements often cause considerable differences due solely to peculiarities of the local geology, a new uncertainty is introduced to increase the difficulty of the task. Obviously the undertaking is too great for solution without the cooperation of scientific agencies of all countries. It is a satisfaction to record that there is a continually increasing number who are finding fruitful ways of contributing the details necessary to complete the picture.

As will be realized, the fascination—we may almost say romance—of the study of these data extends further to the efforts in their accumulation. Observational stations for the study of variations and perturbations must be located in out-of-the-way places even in populous countries to avoid those artificial disturbances arising from widespread use of electrical currents and devices. There is a lack of comfortable traveling conveniences in unexplored regions, despite the automobile, the airplane and the dirigible, though these are all combining to lessen the old difficulties and the time required in getting about.

In this magnetic survey to determine magnetic distribution and secular variation of the Earth's field the Department of Terrestrial Magnetism of the Carnegie Institution of Washington has done much. This extended on land to those countries and regions where there were or are no established magnetic-survey organizations, or where existing agencies for one reason or another welcomed cooperation. Thus, since 1905, almost 200 magnetic exploring expeditions to remote and little-explored regions were made. During 1905–29, also, an intensive magnetic survey of all oceanic areas was executed, for the first four years with the chartered brigantine *Galilee*, and during 1909–29 with the specially constructed, non-magnetic vessel *Carnegie* (Fig. 10). The latter vessel was unfortunately destroyed by a gasoline explosion and fire in Apia Harbor, November 29, 1929, during her last and seventh world-wide cruise. The number of magnetic distribution-stations of the Institution on land and sea now totals nearly ten thousand. During the past decade ten per cent. of these have been reoccupied for secular-variation data.

The secular-variation data being assembled, isomagnetic charts (Fig. 6) may be prepared for various epochs upon which to base theoretical discussions. In succeeding epochs because of secular variation, shifts of the isomagnetic lines have occurred. It is then

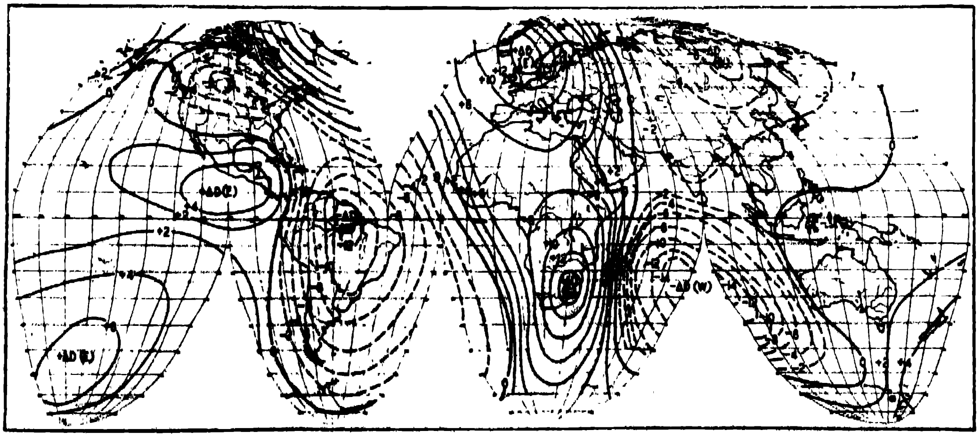


FIG. 11. ISOPORIC CHART FOR DECLINATION

THAT IS, CHART SHOWING LINES OF EQUAL ANNUAL CHANGE, APPROXIMATE EPOCH 1920–25 possible to join by a new set of lines those points past which the isomagnetics—as those of compass-direction or declination—have made the same progress. Thus, for instance, those places at which the declination has changed at the rate of one minute of arc a year, let us say to the eastward, are joined together. The same is done for changes of two minutes, three minutes, and so on up to the maximum rate of change of about one quarter degree, neglecting the immediate vicinity of the magnetic poles. Lines so drawn are called isopors or lines of equal marching. Only recently has it been possible to attempt drawing such isopors for the whole world with any degree of detail (see for example, the isopors of declination in Fig. 11). The picture resulting from these preliminary charts has presented the whole question of secular variation in a new light and has raised questions of broadest geophysical significance.

While it may be true that the rotation of the Earth with its magnetic field reaching out from it and surrounding it like a mantle constantly acted upon by radiations from the Sun and from the depth of space, subjects that field to a progressive precessional effect, what has long been suspected is becoming more and more apparent. A large part of the changes in the characteristics of the magnetic field has its origin not from influences impressed upon it from without, but arises from silent but titanic forces ceaselessly at work deep within the Earth itself. It must have been something of this sort which was in the mind of the Norwegian magnetician of the past century when he said that "the variations of the magnetic needle are a mute language revealing to us the changes perpetually going on in the interior of the Earth." And when we see the rise and fall of the rate of the secular change, the slow expansion and then the gradual retraction of the areas within which there have been excessive alterations in any of the magnetic elements, we realize there are still active changes going on in the Earth's interior.

On the isoporic chart for declination (Fig. 11) drawn for the approximate epoch 1920–25, a line showing no change over the period of a year runs from Nova Zembla off the northern coast of Russia, southward passing east of the Caspian Sea, thence continuing across Arabia and the island of Madagascar. East of this line the north end of the needle is pointing yearly farther west at a rate which increases slowly as the distance from the zero-line is increased, reaching a moderate maximum somewhere in eastern Siberia or Mongolia. The changes in the Indian Ocean are supposed to be larger than in Asia; this region is one where there are but scanty data available. However, to the west of that line of no annual change, over the greater part of Europe and extending somewhat into the Atlantic, there is a region of which we can speak with assurance, and one which presents a very interesting phenomenon. Numerous observatories have kept a continuous record of magnetic changes for nearly 30 years, some much longer, so that for that length of time the picture is for the most part complete. Proceeding westward from the Siberian border, we find the declination-isopors representing annual changes of one minute, two minutes, three minutes, and so on, packed quite closely together so that when we have reached Great Britain and the North Sea the annual rate of change in 1925 was nearly 13 minutes. The area having this large change is relatively small, so that the isopor takes the form of a small closed oval, surrounded by larger ovals successively representing the smaller changes. Along the northern part of Africa the changes are less rapid but in South Africa there is

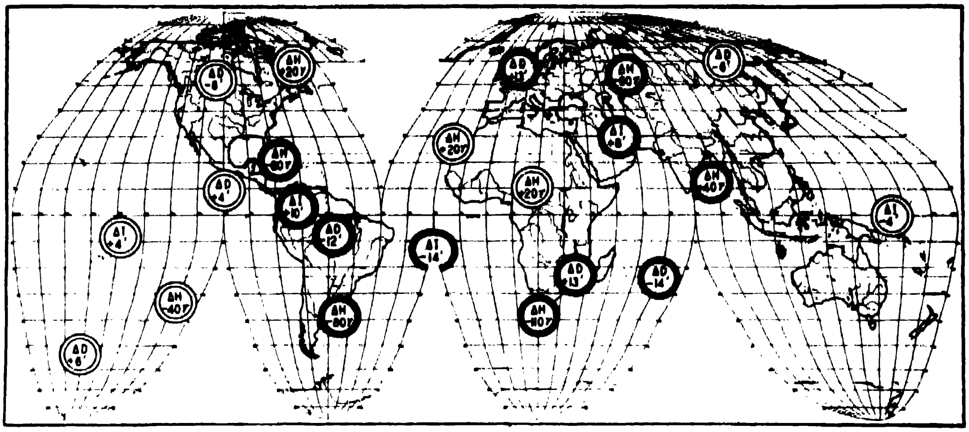


FIG. 12. DISTRIBUTION OF FOCI OF RAPID ANNUAL CHANGE OF THE MAGNETIC DECLINATION, INCLINATION AND HORIZONTAL INTENSITY, APPROXIMATE EPOCH, 1920–25

another focus of rapid change represented by concentric ovals on our isoporic chart. Unfortunately, there are no observatories at the present time in all of Africa south of Helwan near Cairo, so all we know of conditions there has been gleaned from occasional field observations.

But the foci of isopors are not permanent. The center of rapid change in western Europe has developed since the year 1900. If isopors are drawn for one-minute intervals, more than a dozen will be crossed at the present time in going from Ireland to the Ural mountains, whereas in 1905 scarcely more than one or two would have been crossed in the same distance. Now (in 1932) the zero-isopor is as described at about 60° east longitude; in 1905 it was in central Siberia at about 90°. So that while these ovals of our picture are moving outward from a center somewhere north of Scotland much as waves move in a pond from the spot where a stone has fallen into the water, the zero-line as a sort of shore-line against which these waves are beating has moved west to meet them. What the ultimate development of these figures will be we can only surmise, but there is reason to suppose that the dilation of these figures will be followed by a subsequent contraction. In eastern South America across a zero-isopor which passes from Labrador down the Atlantic past Cape Verde and St. Helena, there is a focus of opposite sign to those in Europe and South Africa, and the lines about this focus we know are moving inward. Do the lines move alternately inward and then outward, or do they continue to move inward until the focus disappears, perhaps to reappear elsewhere? We can not answer these questions until time has supplied the necessary knowledge, or until some geographical explanation has been found which will enable us to make a safe prediction.

The foci of isopors characteristic of the charts showing equal annual changes in declination are present also on the corresponding charts for the other elements. The distribution of these foci is noteworthy (Fig. 12). They are practically all found in the hemisphere containing the great land-masses with the intervening Atlantic Ocean. Such foci as are found in the Pacific hemisphere are of but moderate intensity and not well defined. This fact is doubtless significant, though what the significance may be we can only conjecture. This relation of large and rapidly changing

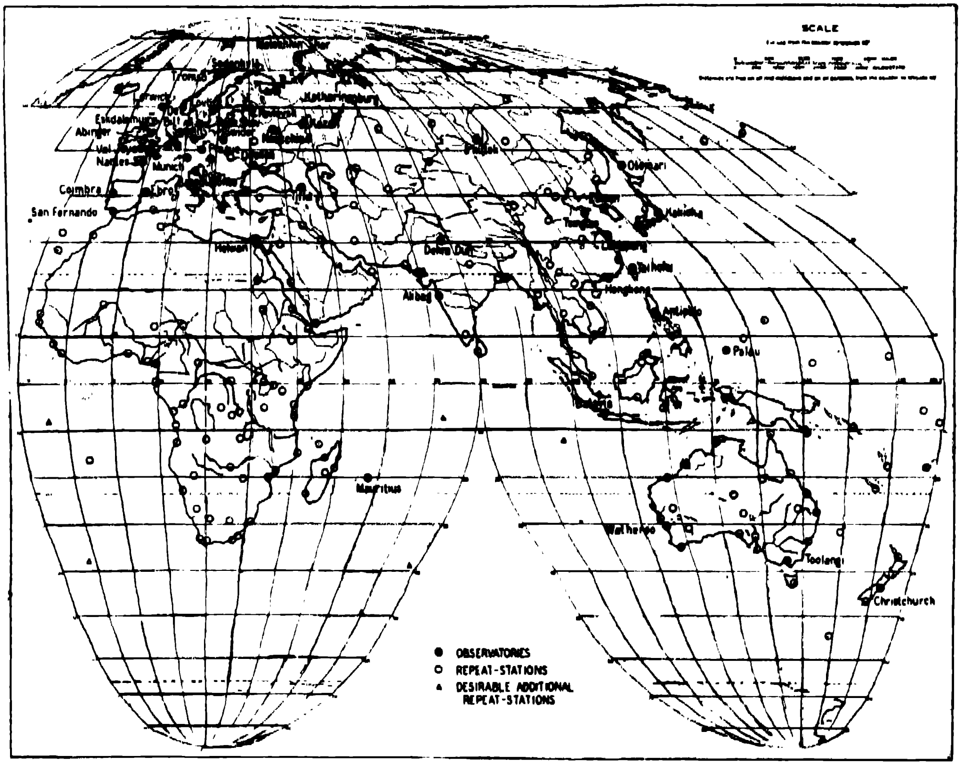


FIG. 13. DISTRIBUTION OF MAGNETIC OBSERVATORIES, REPEAT-STATIONS, AND DESIRABLE REPEAT-STATIONS IN EUROPE, AFRICA, AUSTRALIA AND INDIAN OCEAN

rates of change of the intensity and direction of the magnetic field to the surface structure of the Earth can scarcely be accidental; it is natural to suspect that there is a causal relationship existing between crustal or subcrustal movements and these magnetic manifestations. Perhaps there are changing mechanical stresses, or possibly a changing distribution of internal heat, which in turn affects the direction or magnitude of subterranean electric currents. The phenomenon certainly emphasizes the warning of Maxwell that we must not suppose the inner history of our planet has ended.

The following conclusions have been drawn from the extended mathematical analyses in the Carnegie Institution's Department of Terrestrial Magnetism of data for mean epochs 1842, 1882, and 1922. The main cause of the secular variation arises from a system of forces embedded in the Earth. Secular variation is caused not only by a change in direction of magnetization but likewise by a change in the intensity of magnetization. The average annual decreases in magnetic force have been larger for the southern, or water, hemisphere than for the northern, or land, hemisphere, while the average equivalent intensity of magnetization over land areas is somewhat larger than that over oceanic areas. There appears to be a small decrease each year in magnetization—approximately one fifteen-hundredth part. The Earth's total magnetic field at any one time is apparently attributable to the extent of about 94 per cent. to an internal magnetic system and to an extent of about 6 per cent. to external systems.

DIURNAL-VARIATION

The next important time-change—the solar diurnal-variation—in the Earth's magnetic field was discovered in 1722, at London, by a mechanician and clockmaker named Graham. It is stated that at Louveau, Siam, in 1682, experiments in the presence of the King showed the compass-direction different on seven different days; probably these were made at different times of the day and thus were really the first observed indications of diurnal variation.

The length of time required for collecting the necessary data for the study of the diurnal variation repeated day by day, is more commensurable to man's lifetime and that problem can, therefore, be studied at magnetic observatories within a reasonable time with much more detail than can the slow secular variation. Magnetic research has already yielded correspondingly more definite results in this aspect of the subject and has shown promising lines for future work. And while on one side the search

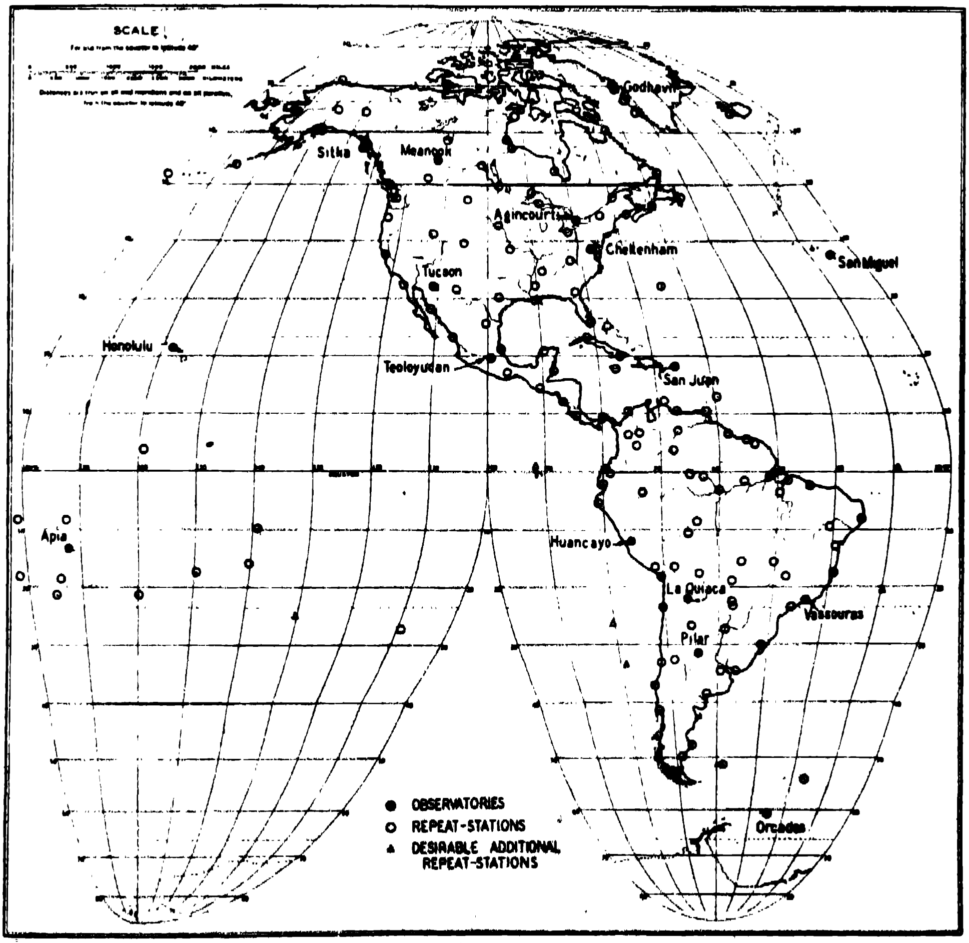
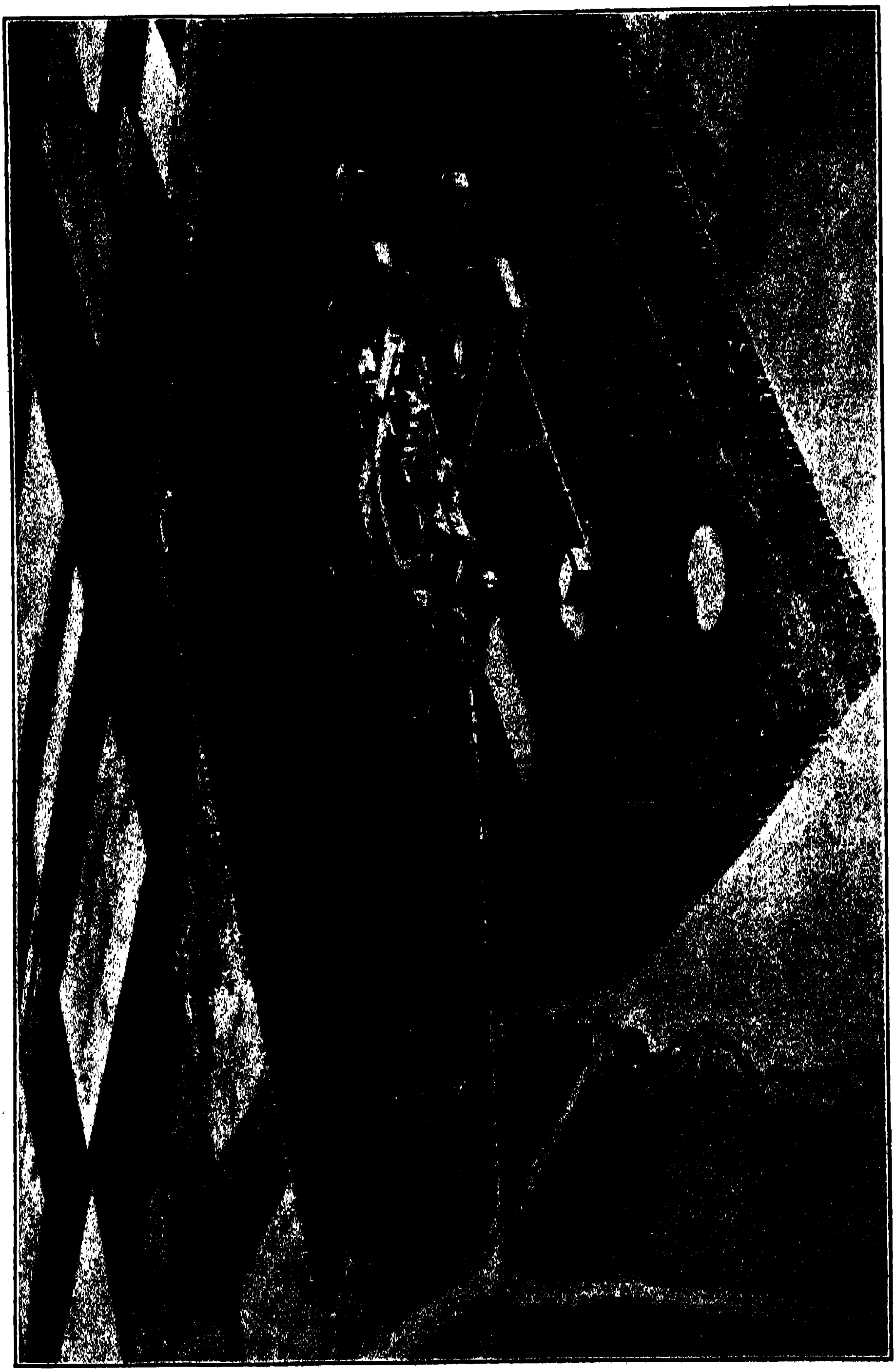


FIG. 14. DISTRIBUTION OF MAGNETIC OBSERVATORIES, REPEAT-STATIONS, AND DESIRABLE REPEAT-STATIONS IN NORTH AMERICA, SOUTH AMERICA AND PACIFIC OCEAN



—*Courtesy of Johnson-Shippee Expedition*

FIG. 14A. SITE AND BUILDINGS OF HUANCAYO MAGNETIC OBSERVATORY FROM THE AIR, APRIL, 1931

for the explanation of the main part of the Earth's magnetic field and its secular variation is hampered by the fact that we know only one planet, namely, our own, and that we have to put up with those irregularities in its crust, that distribution of land and sea which we find upon it, we can on the other side collect data for the diurnal variation for very many days and utilize the natural differences in season, in magnetic disturbance, in sunspot-numbers for testing theories and drawing conclusions.

The world-distribution of existing magnetic observatories is shown by the black dots on Figs. 13 and 14; the open circles and the small triangles on these charts indicate desirable repeat field-stations for the determination of secular variation. From the first chart, showing Europe, Asia, Australia, Africa, and the Indian Ocean, we see how great a majority of the observatories are in Europe. It is especially noteworthy that on the whole of Africa there is only one existing magnetic observatory and that in the extreme northeastern part. When it is recalled that several foci of large secular change are located in Africa, the importance of additional magnetic observatories there is apparent. The second chart shows the distribution of existing observatories in North and South America and in the Pacific Ocean. Such observatories and laboratories have, indeed, been established by forward-looking and scientific-minded nations, and they are an indispensable source of data which the solutions of magnetic questions require. Our own country, through the work of its Coast and Geodetic Survey, has contributed much, especially in the past thirty years through its magnetic surveys of the United States, its territories, and coastal waters, and through the maintenance of five well-distributed observatories. The Institution also established and maintains two magnetic observatories, the one near Watheroo, Western Australia, and the other near Huancayo, Peru (Fig. 14A). The latter is uniquely located on the magnetic equator at an elevation above sea of 11,000 feet, while the former adds a much-needed station in the southern hemisphere.

The diurnal inequality varies with the season of the year, the range of this inequality being greater in summer than in winter. As one goes from temperate zones to the frigid or to the torrid zones, these summer and winter inequalities present widely differing features. The extent to which such an inequality varies throughout the year is readily seen by the graphs in Fig. 15. It will be immediately apparent that diurnal variation in its main features progresses according to local mean time. Thus this variation is connected with the Earth's rotation and, as its major tendency follows the apparent motion of the Sun, it may be presumed that the Sun is an important factor in this daily phenomenon. This variation also is the first indication that the Earth's magnetism responds to outside influences which find their origin in solar activity and act upon the upper regions of the atmosphere. Fig. 16 also indicates how this diurnal variation changes with season, the greatest ranges always occurring in the summer months.

Here in Washington the north end of the compass-needle on a magnetically-quiet day starts swinging eastward, beginning with sunrise, continuing so until some time between 8 and 9 o'clock, when it swings rapidly towards the west until between 1 and 2 o'clock and then returns to its first position. The end of our giant two-mile needle would have an extreme motion in the course of daylight of about 10 to 15 feet; during the night hours its motion would be much slower and much smaller.

The diurnal variation of declination at Watheroo for the year 1930 by seasons yields three curves (Fig. 17) exhibiting

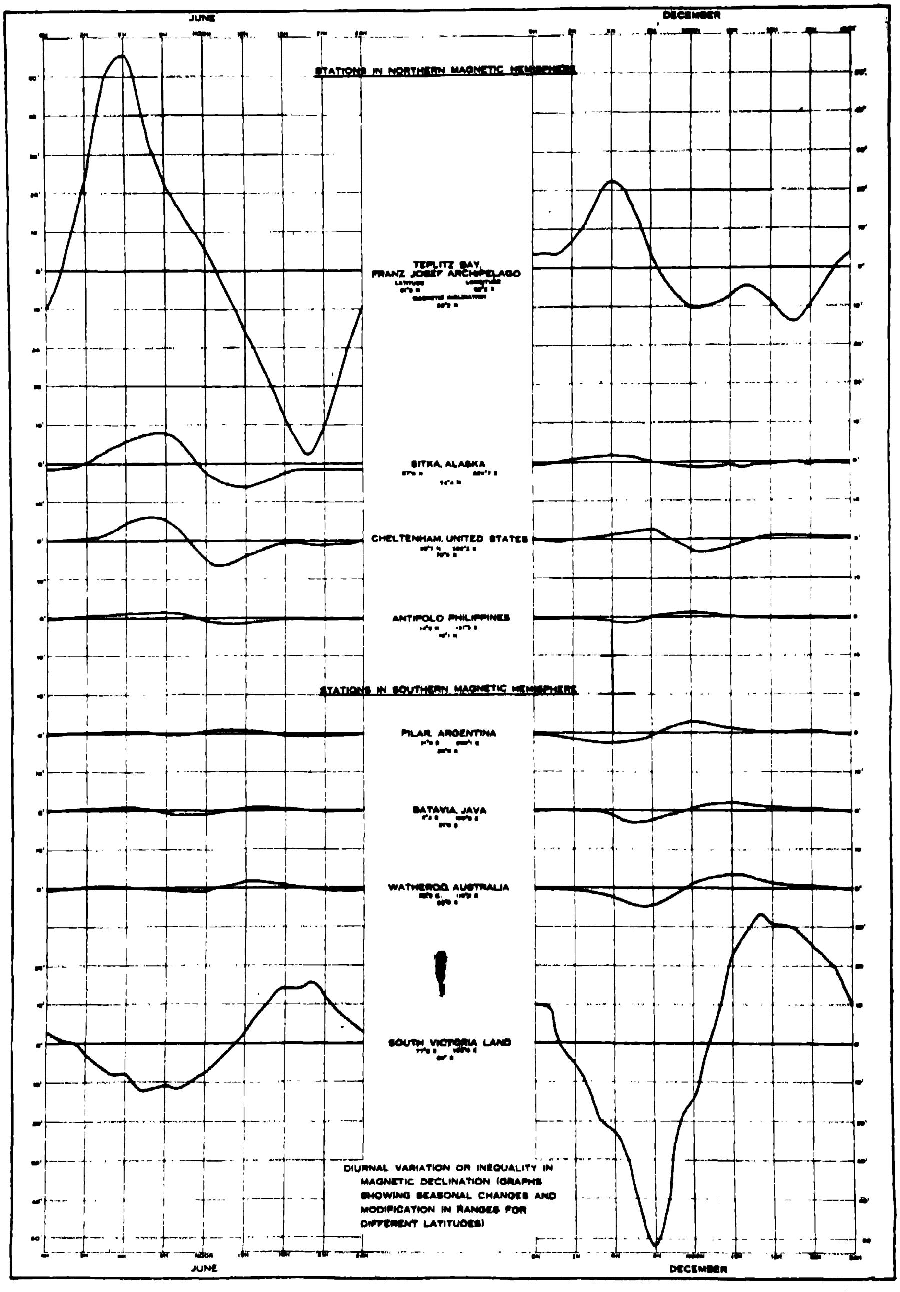


FIG. 15. DIURNAL VARIATION IN MAGNETIC DECLINATION

SHOWING CHANGES FOR DIFFERENT SEASONS IN DIFFERENT LATITUDES—UPWARD MOTION OF THE CURVES INDICATES INCREASING EAST DECLINATION OF THE NORTH-SEEKING END OF THE NEEDLE

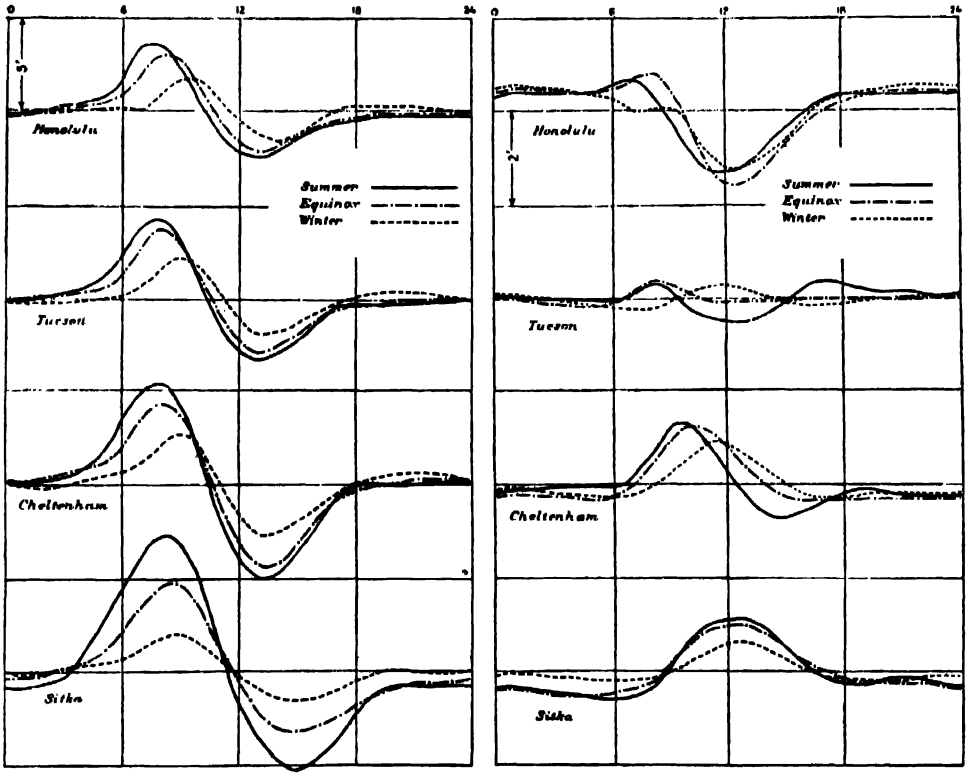


Fig. 16. Diurnal variation of magnetic declination (left) and inclination at Honolulu, Tucson, Cheltenham and Sitka observatories for summer, equinox and winter (after U. S. Coast and Geodetic Survey)

the "southern" type of variation which characterizes a magnetic observatory situated at about 30° south, where the focus of the external electrical current-system causing diurnal variation passes approximately overhead daily. The variation is greatest at the December solstice and least at the June solstice due to the fact that the ionization produced by the Sun is greatest or least respectively over the southern hemisphere at those seasons. At Huancayo, on the magnetic equator, the corresponding graphs (Fig. 18) show the variation at the December solstice, when the Sun is actually south of Huancayo, is of the south temperate type, while when the Sun is over the northern hemisphere the variation is of the north equatorial type. This is an excellent indication of the changes which take place in the overhead current-system from season to season. Instead of moving northward or southward with the seasons as one might expect, this series of curves indicates that the southern current-circuit or the northern current-circuit expands according as the Sun is over the southern or northern hemisphere, so that during the northern summer Huancayo is included in the edge of the northern circuit while during the southern summer it falls well within the southern circuit. Similar phenomena are exhibited by the diurnal variations at Batavia and Apia, other observatories near the magnetic equator.

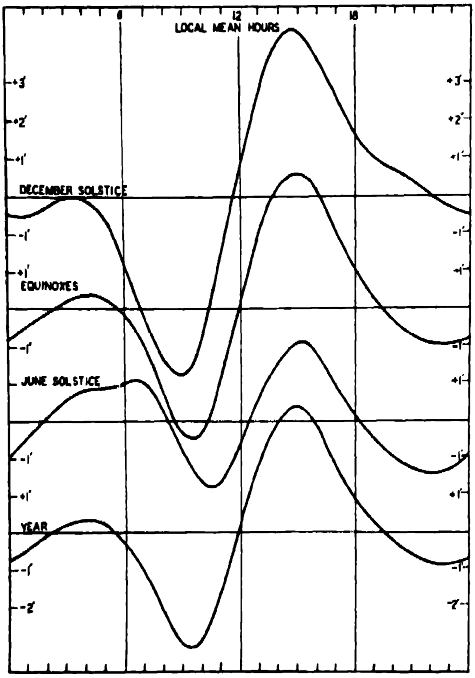


FIG. 17. MEAN SEASONAL AND ANNUAL DIURNAL-VARIATION IN MAGNETIC DECLINATION AT WATHEROO MAGNETIC OBSERVATORY, 1930

SMALLER PERIODIC VARIATIONS—LUNAR-DAY AND ANNUAL

Besides the ordinary diurnal variation there is another, small and quite systematic, namely, that associated with the Moon's position.

We have seen in several figures the average daily influence of the Sun on the magnetic force as revealed by the 24 average hourly mean values for a number of days giving the systematic changes in the course of a solar day, from midnight to midnight, that is, from one lower transit of the Sun to the next. In the same way, we can speak of a lunar day, reckoned from one lower transit of a moon to the next. This interval is, on the average, 50 minutes longer than a solar day; for convenience, we divide it into 24 lunar hours of equal length. By combining the magnetic values for each corresponding lunar hour of a large number of days, we obtain the influence of the Moon on the Earth's magnetic field, that is, the lunar diurnal-variation. The magnitude of the lunar variations is less than one tenth of the solar and can be derived only by careful analysis from very many observations.

While the lunar variation is too small to have practical interest for navigational purposes, it is very important for the investigation of the highest layers of the atmosphere, where these magnetic variations are produced. The simple nature of the lunar variations, the double wave, indicates their tidal origin, that is, their relation to the same forces which cause the familiar regular rise and fall of the water in the ocean and which produce similar and even more regular movements in the atmosphere.

The full significance of the lunar variation is brought out if we calculate it separately for the different phases of the Moon, which are shown in Fig. 19, for

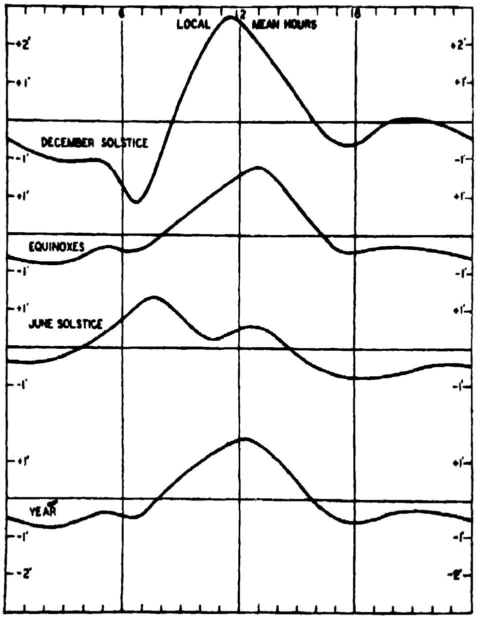


FIG. 18. MEAN SEASONAL AND ANNUAL DIURNAL-VARIATION IN MAGNETIC DECLINATION AT HUANCAYO MAGNETIC OBSERVATORY, 1930

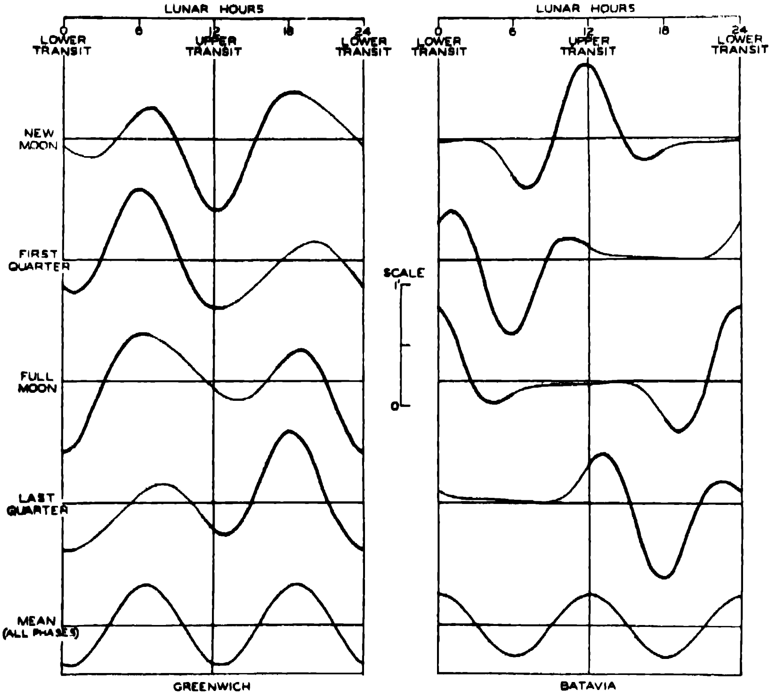


FIG. 19. LUNAR DIURNAL-VARIATION EAST MAGNETIC DECLINATION IN SUMMER

data from Batavia and Greenwich. These curves are based on 63 years of observations, or over 180,000 hourly observations in the four summer months May to August. The greater variation is in daylight hours, this effect of the tidal movements being enhanced by higher ionization, higher conductivity of the atmosphere. From our knowledge of the tidal movements and of the lunar magnetic variations, we can infer the change of ionization in the course of the solar day, and also the different physical state of the atmosphere in the different seasons, in different stages of the sunspot-cycle, and at different degrees of magnetic disturbance. Note that the Batavia and Greenwich curves have opposite phase—Batavia a maximum at transit, Greenwich a minimum—because they are situated on opposite sides of electric current-system in the upper atmosphere which produces them.

It is very likely that lunar variations originate in even higher layers of the atmosphere than the solar variations, because they are so extremely sensitive to changes in magnetic activity as shown in Fig. 20. In Batavia the lunar variation is just as regular on disturbed days as on quiet days, but the range is tenfold as great. The location of an observatory is an important consideration affecting the evidence it provides for the study of this phenomenon. The Institution's observatories at Watheroo and Huancayo are key stations in an investigation on lunar diurnal-variations, the former being in the center of the current-system producing it and the latter on the magnetic equator.

When monthly values of compass-direction are corrected for the progressive secular change, they show a small variation with the year as a period. This, known as the annual variation, is a cyclical change and should not be confused with the annual change which

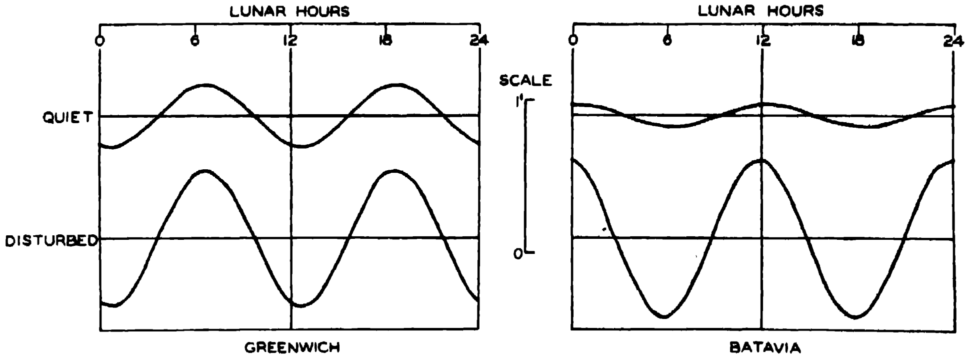


FIG. 20. LUNAR DIURNAL-VARIATION EAST MAGNETIC DECLINATION ON MAGNETICALLY QUIET AND DISTURBED DAYS

means the change in one year due to secular variation. This annual variation is a minute quantity and for stations in North America shows a total range of about one minute of arc. Thus the ends of our giant compass-needle at Washington would oscillate because of this variation during the present year through little more than one foot. So far as investigated, the cause of this variation appears to be outside the Earth.

A study of the time-changes affecting the magnitude and direction of the forces controlling the movement of the compass-needle has shown us that both the Sun and the Moon exert a subtle influence over them, and it is but natural to infer that a similar influence emanates from the planets or from the distant stars. Such a possibility has not been overlooked but so far there is no positive evidence from available data that anything of that kind exists.

REGULAR AND IRREGULAR VARIATIONS AND MAGNETIC ACTIVITY

There are other time-changes of quasi-regular and of irregular types. These are associated with what we call the Earth's magnetic activity or, let us say, its general state of magnetic rest or magnetic unrest.

This magnetic activity at a given station, during any interval, may be defined as a measure for the frequency and intensity of marked irregular deviations—magnetic storms—for example, from the normal diurnal variation, in that interval. There are many ways in which such a definition may be numerically expressed. The simplest and now most generally used is the international characterization. In this every observatory, from inspection of the character of its photographic records, assigns to each 24 hours between successive Greenwich midnights a "character-figure" on a scale 0–1–2. The character "0" applies to quiet, "1" to moderately disturbed, and "2" to greatly disturbed days. The adopted daily values are the averages for all collaborating observatories, the number of which increased from 30, when this measure was begun in 1906, to about 45 in 1932.

A more detailed method of measuring activity is that called the *u*-measure. This depends upon the interdiurnal variability, that is, the average difference regardless of sign, in the force directing the compass between successive daily means.

During days of character 2 our giant two-mile needle will have violent oscillations causing its north end to move through as much as 100 feet here in Washington. At stations in polar regions, these disturbances are more violent because of the proximity of the magnetic poles. Actual records for Arctic stations have been obtained at times which would indicate that the north end of our giant needle would have shifted during such disturbance 20° to 30°—equivalent to a total displacement of its end through distances of about 2,000 to 3,000 feet. When it is borne in mind that such deflections may occur in a few minutes of time, the agitation of the Earth's field during such disturbances is readily realized. All intermediate stages between very quiet and extremely disturbed conditions exist.

Magnetic storms may be classified as having origin due (1) to changes occurring in the regions about the Earth, (2) to changes within the Earth, and (3) to changes within or external to the Earth and with center of field of action at times stationary but generally moving from place to place. Storms of the first type are simultaneous over the Earth. Frequently they are initiated by a sudden sharp shift following comparatively quiet or normal conditions and for this reason are called "sudden-commencement" disturbances. Sudden commencements seem always of an oscillatory character, and in general a tendency to oscillation and continual unrest is one of the most outstanding features. Fig. 21 reproduces the records of disturbed days at the Huancayo and Watheroo observatories, December 3–5, 1929. Fig. 21A shows records obtained on the same days at Little America, where the Institution cooperated with the Byrd Antarctic Expedition in maintaining a temporary magnetic observatory.

Storms of the second type are sometimes associated with great volcanic out-

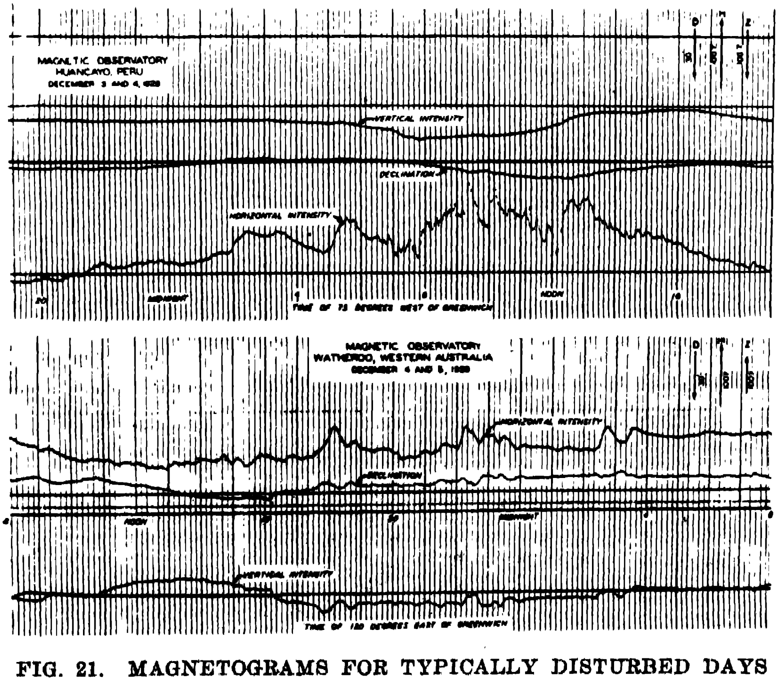


FIG. 21. MAGNETOGRAMS FOR TYPICALLY DISTURBED DAYS AT THE HUANCAYO AND WATHEROO MAGNETIC OBSERVATORIES, DECEMBER, 1929

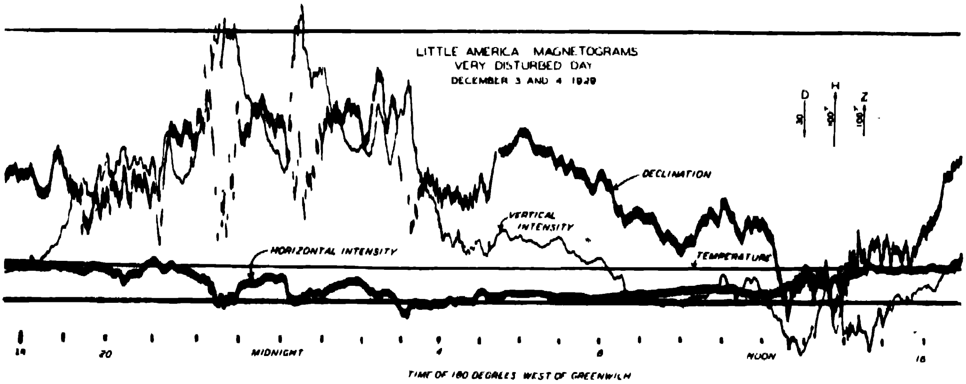


FIG. 21A. MAGNETOGRAM FOR TYPICALLY DISTURBED DAY AT LITTLE AMERICA, ANTARCTIC CONTINENT, DECEMBER, 1929

bursts as was the case for the eruption in Martinique in May, 1902, evidenced as world-wide by the magnetograms of many observatories. Fig. 22 reproduces records of the compass-directing magnetic force at 21 observatories. The third type is usually represented by a rather slowly developing "bay" on the record extending over a half-hour or somewhat more.

Thus disturbed or quiet magnetic conditions nearly always affect the whole Earth simultaneously. The possibility of any connection between disturbances of the Earth's magnetic field and the weather is excluded since weather is so distinctly local and so different all over the world. But polar lights—the aurorae—are always seen in polar regions when magnetic storms occur. See Figs 23, 23A and 23B for photographs of auroral displays of several types off Siberia. Since the height of polar lights has been determined to be in no case less than 50 miles above the ground, the conclusion is drawn that the magnetic variations and disturbances also have their origin in electrical phenomena taking place at least at greater heights in the atmosphere. This has been confirmed in every respect and the study of the magnetic variations is one of our main sources of information about the constitution of and the phenomena in these outermost and inaccessible regions of the atmosphere.

It was demonstrated in 1908 by Hale at the Mount Wilson Observatory of the Carnegie Institution that the Sun possesses a total magnetic field perhaps 50 times that of the Earth. But a field of that intensity is far too weak to make its magnetic influence felt at the Earth, 93,000,000 miles distant. It is much more probable that solar influences on the Earth's magnetism are connected with enormous streams or clouds of particles, atoms, ions, and electrons ejected from the active regions of the Sun, which travel through space and from time to time reach the Earth after one or two days, impinge its atmosphere, causing magnetic storms, which often disturb electrical communications. These particles, like the wave-radiations mentioned above, do not reach the Earth's surface but are stopped by the air before they come lower than 50 miles and cause inductively some of the observed effects in currents in the air and in the Earth. Thus one may conceive magnetic disturbance-features as the result of "messages from space."

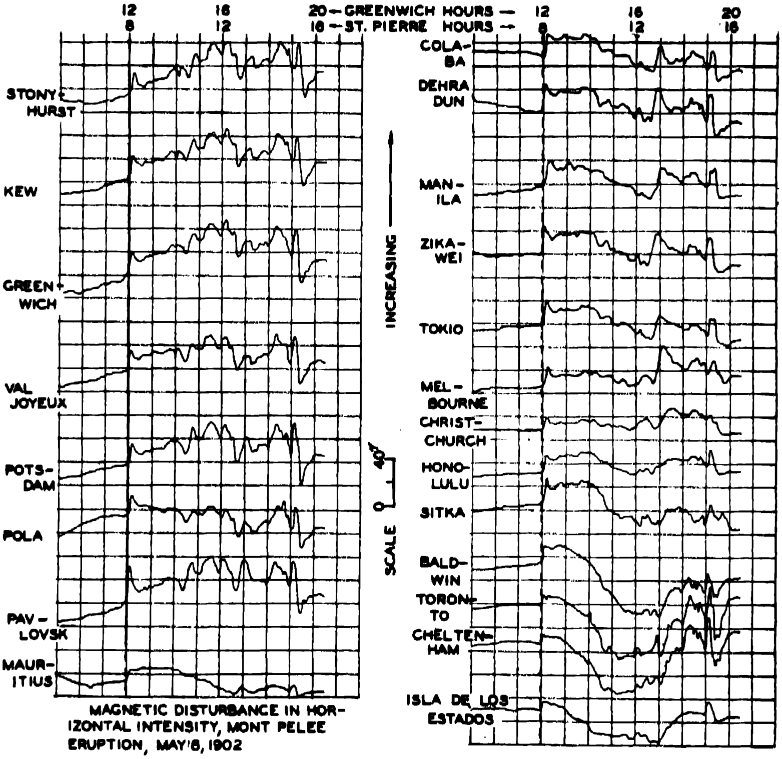


FIG. 22. SUDDEN-COMMENCEMENT MAGNETIC DISTURBANCE OF MAY 8, 1902, BEGINNING AT TIME OF MONT PÉLÉE ERUPTION

The regular daily magnetic variation apparently is the effect of other radiations from the Sun, which are absorbed in the highest levels of the air, and which make these layers electrically conducting. These conclusions drawn many years ago from magnetic observations became more important after the invention of wireless telegraphy, because with them we may explain why wireless waves are bent around the Earth along these same conducting layers.

The range of diurnal variation varies with magnetic character—a feature brought out in Fig. 24. Statistical studies have led to the identification of three phases in the progress of a disturbance, (1) strengthening of the ordinary diurnal movement according to local time, (2) everywhere a similar but unequal course according to universal time, and (3) a periodic damped wave dying out in the post-perturbation.

Magnetic activity provides one of the means of determining another time-change, namely, that of an 11-year period apparently agreeing with the well-known period in sunspot-frequency (Fig. 25). Latest investigations have shown, however, that solar activity as indicated in its reflected effect in the magnetic field is not completely or always represented by sunspottedness or other phenomena which astrophysicists observe on the Sun's surface; magnetic observations apparently reveal distinct solar influences of another kind and add in this way to our knowledge of solar physics.

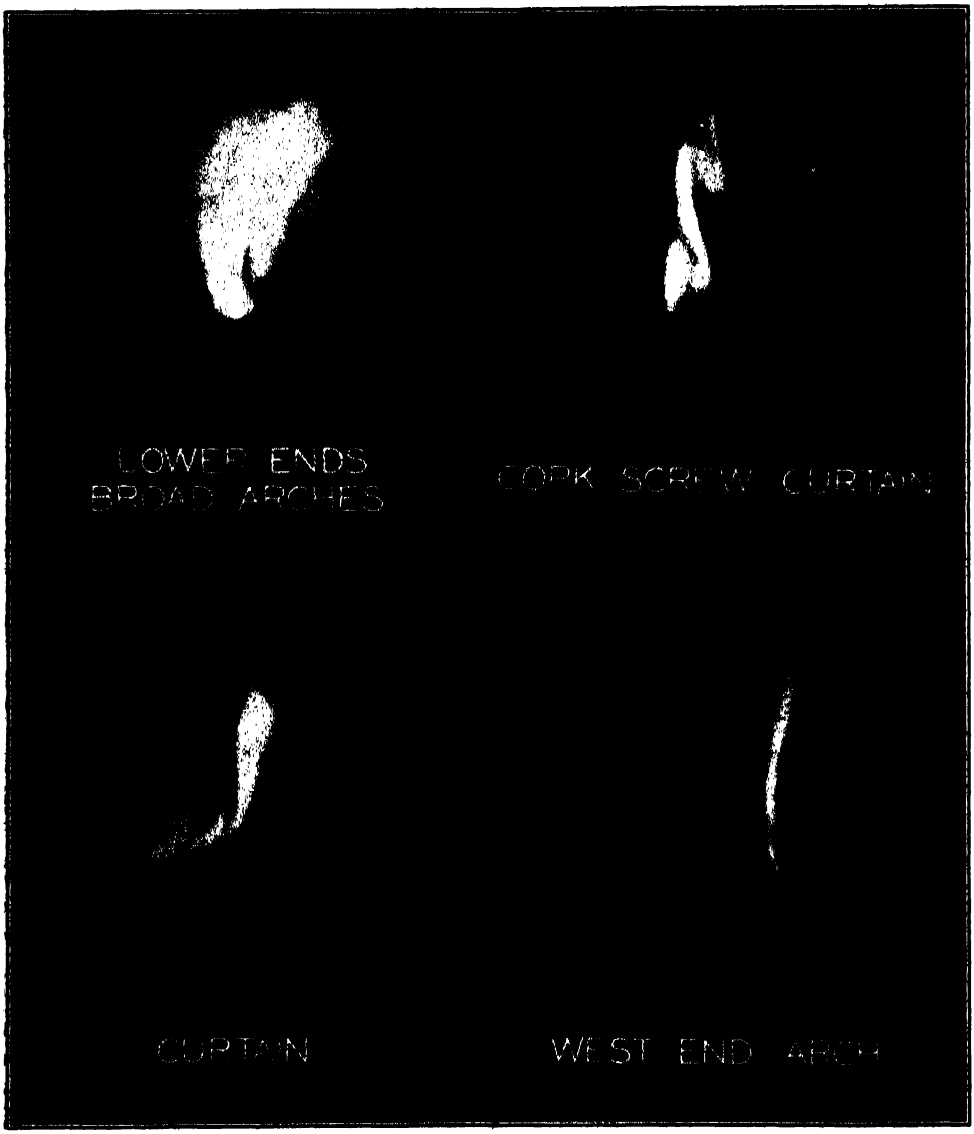


FIG. 23. TYPES OF AURORAL LIGHTS FROM PHOTOGRAPHS MADE OFF THE NORTH COAST OF SIBERIA

As the Earth revolves about the Sun during the year there are corresponding fluctuations in magnetic activity, the maximum or crest occurring during the equinoctial months of March and September, and the minimum or trough in the solstitial months of June and December. This annual variation of magnetic activity, shown by Fig. 26, was deduced from the examination of 59 years of observations, 1872–1930, at a number of observatories. The graphs result from grouping the data in thirds according to high, average, and low activity.

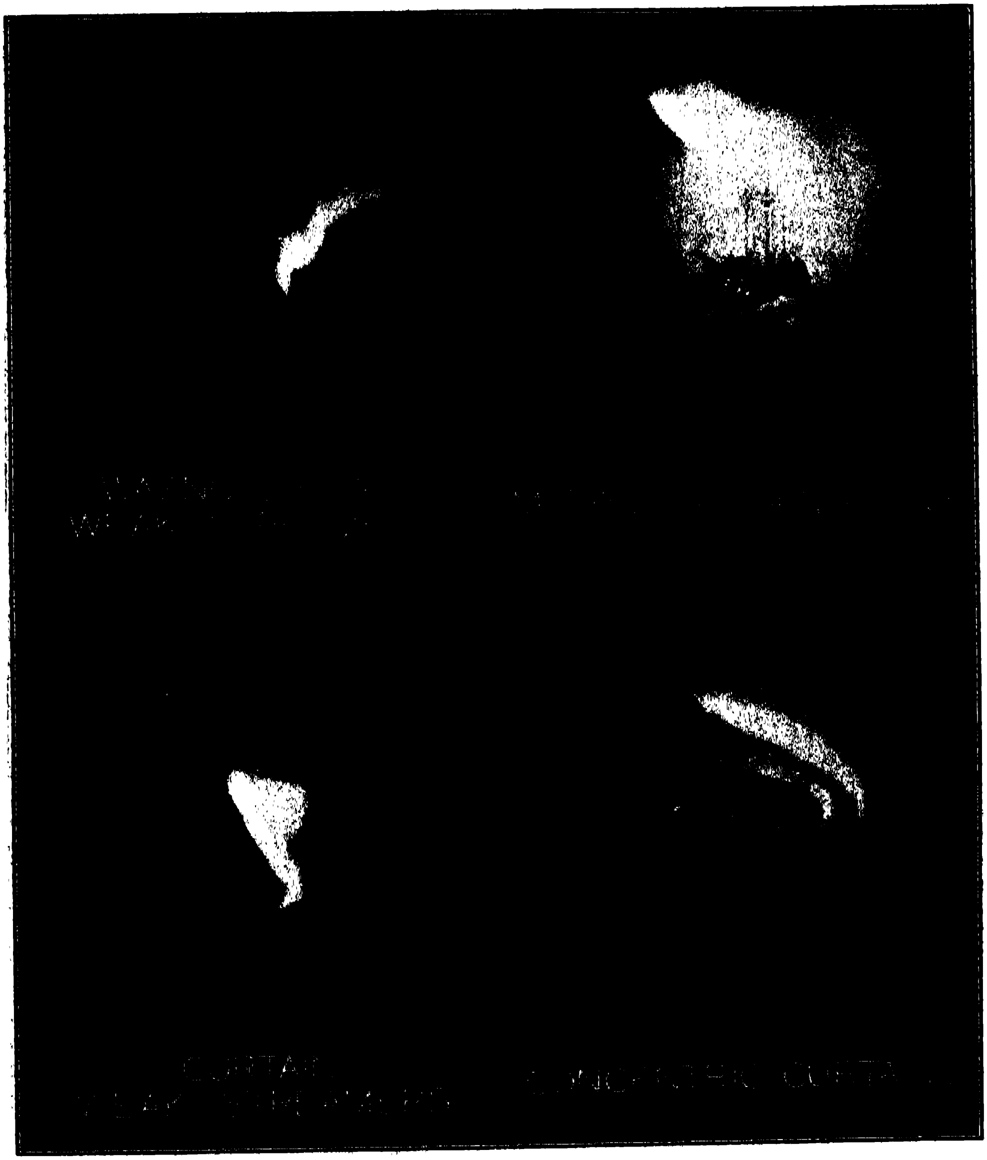


FIG. 28A. FURTHER PHOTOGRAPHS OF AURORAL LIGHTS

Another time-change related to magnetic disturbances is shown by Fig. 27, for an interval chosen at random, the consecutive averages of magnetic force over 24-hour intervals centered at 0^h, 6^h, 12^h, and 18^h Greenwich mean time for three widely separated stations—Seddin (near Potsdam, Germany), Huancayo (Peru), Watheroo (Western Australia). The three curves are strikingly similar showing typical depression during a disturbance followed by gradual recovery to normal value afterwards. Obviously the *u*-measure which is derived from

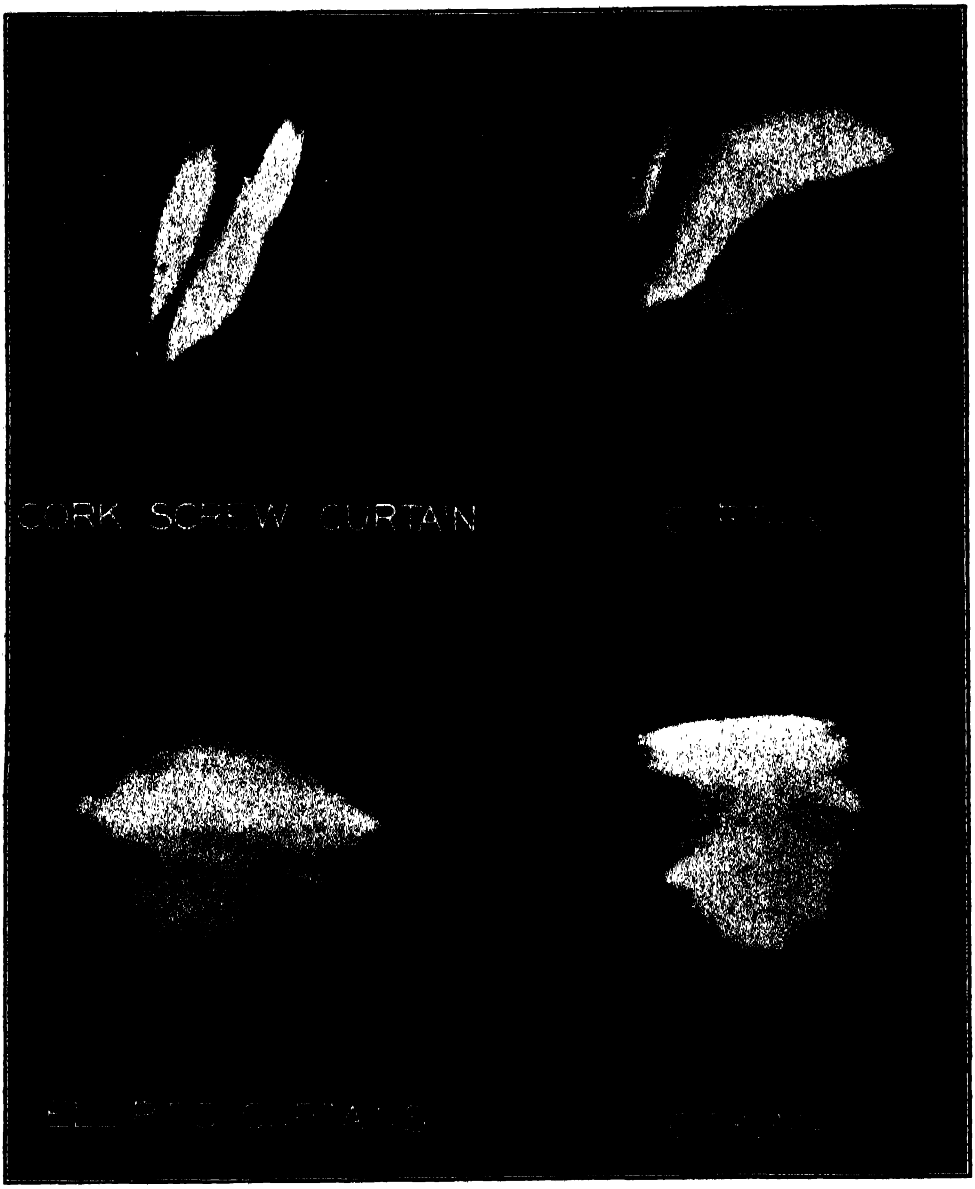


FIG. 23B. FURTHER PHOTOGRAPHS OF AURORAL LIGHTS

such systematic changes must be representative of the world-wide magnetic activity.

PULSATIONS

Another type of irregular disturbance is that known as micropulsations first noted by Eschenhagen and which appear to be of about the same magnitude at different locations on the Earth. These are of very short periods such as 5 to 15 seconds of time. It has been proposed (Störmer, 1906) that these short-period

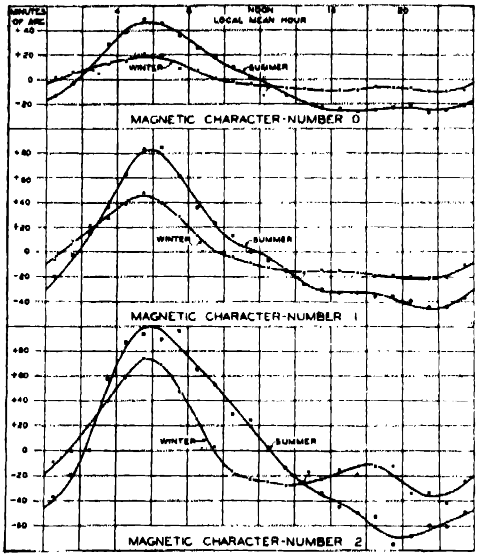


FIG. 24. CORRELATION BETWEEN DAILY VARIATION OF COMPASS-DIRECTION AND MAGNETIC ACTIVITY AT CAPE CHELYUSKIN, SIBERIA, OCTOBER, 1918, TO AUGUST, 1919

and small-amplitude pulsations may be explained in the world-wide sense as the electromagnetic effects of clouds of electrically charged particles moving in periodic orbits around the Earth. On the other hand, there are recorded at observatories in regions of comparatively limited area a giant type of pulsation with periods of as much as one and one-half to two minutes of time and ranges from 10 to 20 times as great. At the present time there is apparently such an area near Scandinavia. Fig. 28 shows records of giant pulsations obtained September 10 and 12, 1930, at Abisko, Swedish Lapland, and September 12, 1930, and September 19, 1931, at Tromsö, Norway. Tromsö is something over 90 miles north of Abisko. At two other observatories 215 and 370 miles, respectively, from Abisko the ranges recorded were considerably reduced, while they were found to be very minute or negligible at observatories distant about 1,000 miles or more. On account of the relatively local character of these giants, they can hardly be explained as suggested above for the normal small-amplitude pulsations. They may, therefore, reasonably be ascribed to peculiar currents now prevailing in the atmosphere above the northern part of Scandinavia or to a deeper penetration at times into the atmosphere there of Störmer's electrified "flying clouds." That such giant micropulsations are of local cause is indicated also since at other observa-

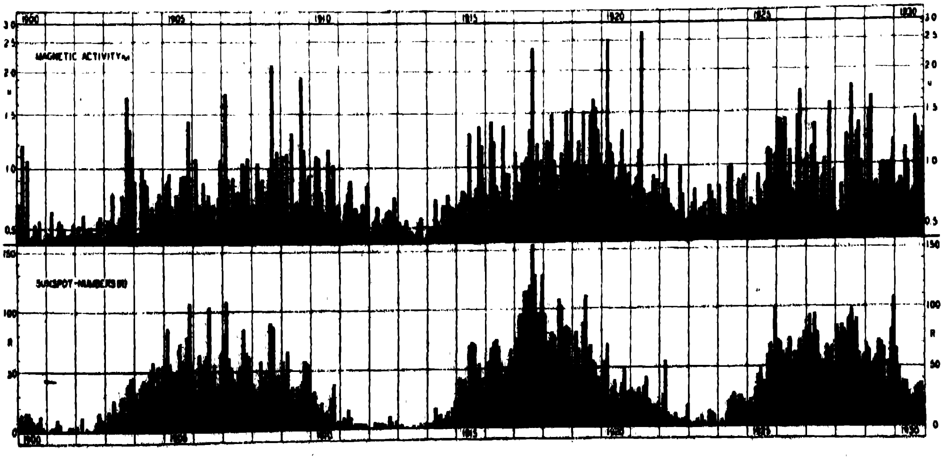


FIG. 25. MONTHLY MEANS OF MAGNETIC ACTIVITY AND OF SUNSPOT-NUMBERS, 1900–30

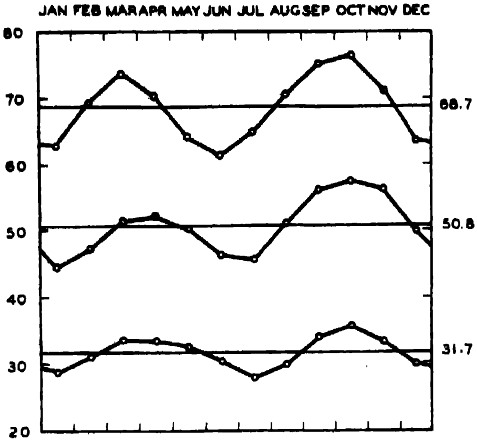


FIG. 26. ANNUAL VARIATION OF MAGNETIC ACTIVITY, 1872–1930, AVERAGED ACCORDING TO HIGH, AVERAGE AND LOW ACTIVITIES

tories they may be occasionally recorded for a period of years and then cease. Thus Professor Nippoldt at Potsdam, Germany, states that giant micropulsations "went to sleep" in 1903 and have since been very rare there.

CONCLUSION

This complexity of the magnetic time-change phenomena has baffled attempts at theoretical explanations or hypotheses although long the field of able and enthusiastic investigators. We may hardly hope in our time to lay down a general theory which will explain the multitude of observed facts or permit us to foretell with any precision future changes. Despite this, magnetic observations have already added materially to our knowledge of the Earth's interior, particularly to some of the geological features of its crust. Thus secular-variation changes within the crust indicate an interior

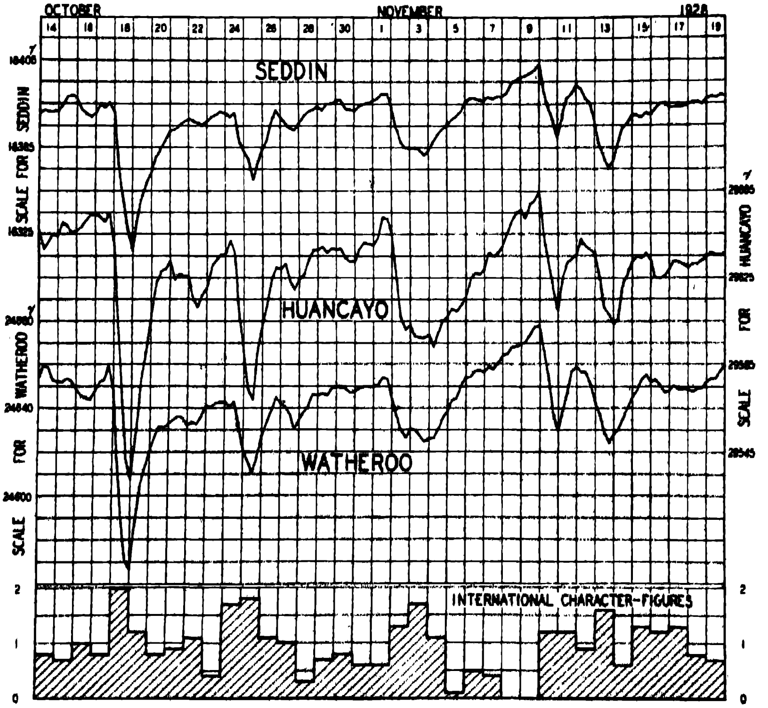


FIG. 27. TYPICAL DEPRESSION (POST-PERTURBATION EFFECT) FOLLOWING MAGNETIC DISTURBANCES AS SHOWN BY DATA FROM THE SEDDIN, HUANCAYO AND WATHEROO OBSERVATORIES, OCTOBER 14 TO NOVEMBER 19, 1926, WITH GRAPH OF INTERNATIONAL CHARACTER-FIGURES FOR THE SAME PERIOD

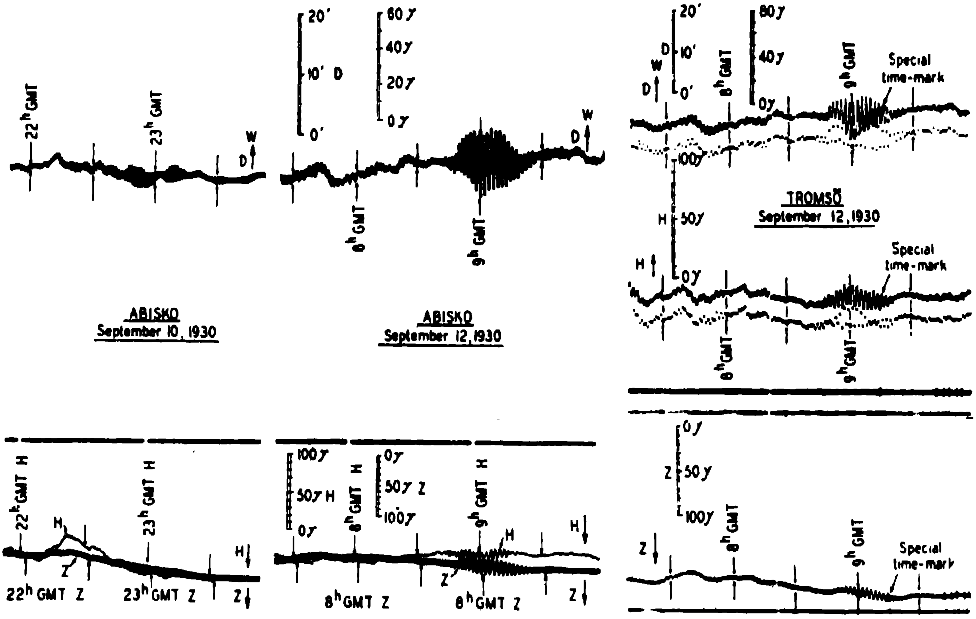


FIG. 28. RECORDS OF MAGNETIC PULSATIONS AT ABISKO AND TROMSÖ, SEPTEMBER 10, 12 AND 30, 1930

more mobile than the exterior layers, not only as a whole but regionally. Even more definite and promising are the results of those magnetic researches which give us also additional information regarding the high atmosphere above the Earth.

We must continue looking to observations and to their discussions perhaps more than to pure theory for further advance in knowledge of the causes and laws governing magnetic time-changes, as well as to provide foundations upon which tests may be made of theory. The rapid developments in physics and in atomic physics during the past decade, particularly in ionization, radioactivity, and high-vacuum electrical research, will permit speculations on the origin and changes of the Earth's magnetic field, which must materially advance fundamental conceptions of the nature and of the constitution of matter.

Some papers bearing on time-changes in the Earth's magnetic field are as follows:

L. A. Bauer, "Principal Facts of the Earth's Magnetism and Methods of Determining the True Meridians and the Magnetic Declination." Washington, D. C., U. S. Coast Geod. Surv., 100 pp. with illus. (1902). [Reprinted with slight changes, 1909, 1914, and 1919.]

D. L. Hazard, "The Earth's Magnetism." Washington, D. C., U. S. Coast Geod. Surv., Ser. No. 313, 52 pp., 1925.

J. A. Fleming, "The Magnetic and Electric Survey of the Earth: Its Physical and Cosmical Bearings and Development." *J. Wash. Acad. Sci.*, 16, 109–132 (1926).

G. Angenheister and J. Bartels, "Das Magnetfeld der Erde." Wien-Harms, *Handbuch der Experimentalphysik*, 25, I, 527–684, 1928.

L. A. Bauer, "Beiträge zur Kenntnis des Wesens der Säkular-Variation des Erdmagnetismus." (Dissertation, Univ. Berlin.) Berlin, Mayer und Müller, 54 pp., 1895.

H. W. Fisk, "Isopors and Isoporic Movements." Union Géod. Géophys. Internat., Sect. Mag. Electr. Terr., *Bull.* No. 8, 280–292, 1931.

A. Schuster, "The Diurnal Variation of Terrestrial Magnetism." Phil. Trans. R. Soc., A, 180, 467–518, 1889; 208, 163–204, 1908.

W. van Bemmelen, "Die Lunare Variation des Erdmagnetismus." Met. Zs., 29, 218–230, 1912.

S. Chapman, "The Lunar Diurnal Magnetic Variation at Greenwich and other Observatories." Phil. Trans. R. Soc., A, 225, 49–91, 1925.

S. Chapman and A. T. Price, "The Electrical and Magnetic State of the Interior of the Earth, as Inferred from Terrestrial Magnetic Variations." Phil. Trans. R. Soc., A, 229, 427–460, 1930.

Terrestrial Magnetism and Atmospheric Electricity. An international quarterly journal. Published by the Johns Hopkins Press, Baltimore, Md. Volume 37 now in progress. Contains articles dealing with all branches of terrestrial magnetism and atmospheric electricity.

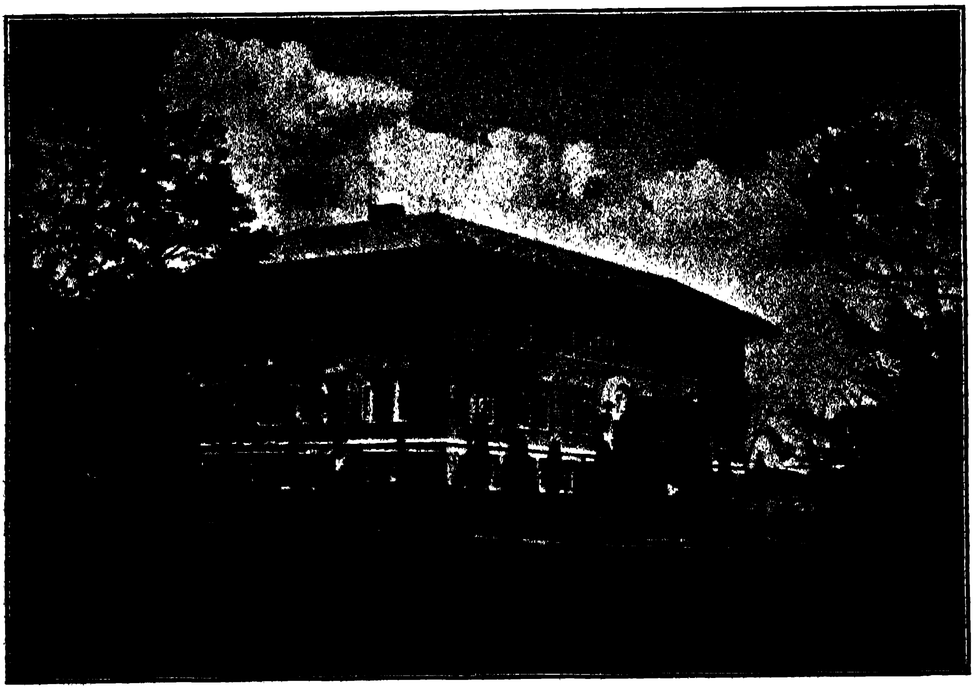


FIG. 29. LABORATORY OF THE DEPARTMENT OF TERRESTRIAL MAGNETISM, CARNEGIE INSTITUTION.

THE CLINICAL APPLICATION OF BLOW-FLY LARVAE

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INTRODUCTION

ONE of the most fascinating developments in modern medical history has been the recent clinical application on a scientific basis of the larvae of the blow-fly. Contributing largely to this fascination, of course, is the conception of this insect playing a beneficial rather than a harmful rôle with respect to human disease. Whereas efforts were formerly directed wholly towards fly control and fly destruction, increasing interest is centering on methods of optimum year-round breeding and, what is practically a new field, methods of producing larvae free from bacterial contamination. In fact, this latter movement has gained such an impetus that the Bureau of Entomology, U. S. Department of Agriculture, is conducting an extended investigation of the blow-fly in its new relation to medicine.

HISTORICAL

Although due recognition must be given to Dr. William Stevenson Baer for having the courage to treat patients with maggots in civilian practice and for carrying out the pioneer work necessary to make the treatment available to the medical profession, the observation that maggots are helpful in curing disease had been made previously, as evidenced by notes in the literature. In retrospect it is interesting to review these briefly.

After the battle of St. Quentin (1557), Ambroise Paré

> found the wounds excessively fetid and full of worms with gangrene and corruption; . . . For more than half a league around the earth was covered with dead bodies, . . . we were the cause of a rising up from the bodies of a great number of large flies gendered by the moisture of the bodies and the heat of the sun; they had green and blue bellies and when they were in the air they cast a shadow on the sun. It was wonderful to hear them buzzing, and wherever they settled they made the air pestilent and there they caused the pest.

D. J. Larrey, the famous military surgeon of Napoleon's armies, notes with respect to the French campaign in Syria (1799) in his "Memoirs of Military Surgery":

> During the progress of suppuration, the patients were only troubled by worms or larvae of the blue flies common in Syria. The hatching of the eggs, which these flies constantly deposit in the wounds or dressings, was assisted by the heat of the weather and by the quality of the dressings, which were of cotton, which alone could be procured in this country. The presence of these insects in the wounds appeared to accelerate their suppuration; but they caused a disagreeable pruritus, and obliged us to dress them three or four times a day. They are produced in a few hours, and increase with such rapidity that in the course of a night they grow to the size of the barrel of a small quill. It is necessary, at each dressing, to use lotions of a strong decoction of rue with a small portion of sage, which destroys them; but they were soon reproduced for want of proper means to prevent the approach of the flies and to destroy their eggs. Although these insects were troublesome, they expedited the healing of the wounds by shortening the work of nature, and causing the sloughs to fall off.

In his "Curiosities of Medical Experience," J. C. Millingen writes:

> During the retreat of our troops after the battle of Talavera (1809), I found the wounds of many of our men, that had not been dressed for three or four days, pullulating with maggots. This was not the case with the Spanish soldiers, who, to prevent this annoyance, had poured olive oil upon their dressings. I invariably resorted to the same practice when I subsequently had to remove the wounded in hot weather.

Perhaps the first intentional use of maggots may be ascribed to J. F. Zacharias, a surgeon in the Confederate Army, who writes of his Civil War experiences:

> During my service in the hospital at Danville, Virginia, I first used maggots to remove the decayed tissue in hospital gangrene and with eminent satisfaction. In a single day they would clean a wound much better than any agents we had at our command. I used them afterwards at various places. I am sure I saved many lives by their use, escaped septicemia, and had rapid recoveries.

About 30 years ago there was a famous surgeon in South Chicago whose name was Larkin. Whenever dressings became filled with maggots in the summer time, it was his practice to remove the dressing, clean off the wound with alcohol, brush the maggots into the wound, and re-apply the dressing. His results were good and the treatment was used not only in osteomyelitis but in chronic septic cases as well.

Thus I might go on citing many other experiences, but Dr. Baer's original observation overshadows all the others in its intensity. Lest any of the graphic details might be omitted, I shall relate it in his own words:

BAER'S ORIGINAL OBSERVATION

> During the late World War an observation which I made among the wounded soldiers led me to believe that the prevention of an infection and the curing of an infection could be brought about by means other than chemical. At a certain battle during 1917, two soldiers with compound fractures of the femur and large flesh wounds of the abdomen and scrotum were brought into the hospital. These men had been wounded during an engagement and in such a part of the country, hidden by brush, that when the wounded of the battle were picked up, they were overlooked. For seven days they lay on the battlefield without water, without food, and exposed to the weather and all the insects which were about that region. On their arrival at the hospital I found that they had no fever, and that there was no evidence of septicemia or blood poisoning. Indeed, their condition was remarkably good, and if it had not been for their starvation and thirst, we would have said they were in excellent condition. When I noticed the extent of the wounds, of the thigh particularly, I could not but marvel at the good constitutional condition of the patients. At that time, the mortality of compound fractures of the femur was about 75 to 80 per cent. even when the wounded had the best of medical and surgical care that the Army and Navy could provide. . . . This unusual fact quickly attracted my attention. I could not understand how a man who had lain on the ground for 7 days with a compound fracture of the femur, without food and water should be free of fever and of evidences of sepsis. On removing the clothing from the wounded part, much was my surprise to see the wound filled with thousands and thousands of maggots, apparently those of the blowfly. These maggots simply swarmed and filled the entire wounded area. The sight was very disgusting and measures were taken hurriedly to wash out these abominable looking creatures. Then the wounds were irrigated with normal salt solution and the most remarkable picture was presented in the character of the wound which was exposed. Instead of having a wound filled with pus, as one would have expected, due to the degeneration of devitalized tissue and to the presence of the numerous types of bacteria, these wounds were filled with the most beautiful pink granulation tissue that one could imagine. There was practically no bare bone to be seen and the internal structure of the wounded bone, as well as the surrounding parts, was entirely covered with the pink, rosy granulation tissue which filled the wound. Bacterial cultures were made, and, while one found a few staphylococci and streptococci still remaining, they were very few in number and not sufficient at that time to cause pus formation. These patients went on to healing, notwithstanding the fact that we removed their friends which had been doing such noble work.

PIONEER INVESTIGATION

The experience just cited made an indelible impression on Dr. Baer's mind. In September, 1928, four children came to the Children's Hospital School, Baltimore, each one of whom had been operated on three or four times for chronic osteomyelitis and treated over a period of from one to five years. Being baffled by the means usually employed in treating such cases, Dr. Baer thought it time to put to practical use the observation he had made on the battlefield. First, a thorough operation was performed with removal of all dead tissue that was accessible. No antiseptics or chemicals of any kind were used, since it was desired to give the maggots full credit for any improvement that might be noted. Larvae of the blow-fly were obtained from the immediate neighborhood and without any attempt at sterilization they were placed in the wounds. At the end of about six weeks, the wounds had entirely healed, not only in the deeper structures but even as to the skin.

In some of the early cases, however, certain secondary infections, particularly those caused by anaerobes, were encountered. In three cases gas bacilli were found in the wound. This was disconcerting, but the patients showed no clinical evidence of gas gangrene. However, experiments were discontinued until the problem could be solved. Six guinea-pigs were inoculated with gas bacilli and then treated at various intervals with maggots. All these guinea-pigs made a rapid recovery with complete function in the infected parts. Therefore, gas gangrene infection was not feared and treatment was resumed until suddenly tetanus (lockjaw) bacilli were discovered in eight cases. All wounds were immediately washed out and the patients given tetanus antitoxin. Four cases showed no clinical symptoms, but two progressed to severe lockjaw. One of these who had advanced tuberculosis died, notwithstanding the administration of large doses of antitoxin. The other case finally made a complete recovery after a long bitter struggle against the infection. It was then realized that in civil practice it would be necessary to have sterile maggots, and that to insure a constant supply, both winter and summer, flies would have to be bred in the laboratory.

At first attempts were made to sterilize the maggot itself, but this proved difficult and the conclusion was reached that organisms were carried in the intestinal tract where they were inaccessible to the sterilizing solution. A technique was then devised whereby the fly eggs were disinfected in a bichloride of mercury solution and the hatched maggots were proved by bacterial cultures to be free from organisms. Using larvae disinfected in this manner, Dr. Baer proceeded with the treatment of chronic osteomyelitis until his death in April, 1931, when he had accumulated well over 200 cases with 95 per cent. cures in children and 85 per cent. cures in adults. His pioneer work was so well carried out and the fame of his clinic spread so far that even his death did not diminish the increasing interest in maggot therapy. To-day the treatment is being applied throughout the United States, with several hospitals raising their own maggots, and the success attained in this country has prompted inquiries from surgeons in such far distant localities as Sweden and the Philippine Islands.

Breeding of Flies

A constant supply of fertilized eggs for disinfection is insured only by careful attention to methods of fly breeding. We have found environmental factors, particularly temperature and humidity, to be fairly important and therefore our incubators are regulated for a temperature of 80° and a humidity of 50 per cent. At first ventilation was thought to be essential, but experience has not shown this to be the case. Artificial illumination is provided by spacing electric light bulbs between the side windows of the incubators. At one time in our early work we resorted to ultra-violet light as a stimulus for egg-laying, but under normal conditions ultra-violet irradiation is not necessary.

The most satisfactory type of fly cage is one of light wooden framework with a durable mosquito net covering. A small door allows the passage of a Petri dish containing food in and out of the cage and at the side of the door a hole is bored just large enough to accommodate a glass vial. Daily rations for the flies consist at present of a sugar-water mixture in which the white of an egg is whipped. The tendency for the flies to drown in the fluid is obviated by placing a piece of porous sponge rubber in the dish. We have tried out various types of foods, including yeast, strained honey, orange juice and ripe banana, but the recipe now in use seems to answer best the requirements for readily available carbohydrate and protein. For the purpose of egg-laying, the flies are provided with a strip of meat folded several times on a toothpick and placed in the glass vial. The folding of the strip is intended to humor the flies, since they endeavor to hide their eggs among the wrinkles of the meat. Raw beef is used by most laboratories, but we have found hog spleen to be more nutritious and more conducive to good egg-laying.

Our studies have been concerned wholly with two species of the blow-fly—Phormia and Lucilia, which I transported from Baltimore a year ago as eggs and pupae. In our laboratory the stages in the life cycle have proved to be quite variable. The eggs hatch in 8 to 24 hours, average 16 hours; the larvae reach maturity in 5 to 9 days, average 7 days; they remain in the inactive prepupal state for a few days before gradually transforming into pupae. The average duration of the pupal stage is six days. Oviposition takes place within five to seven days after the flies emerge and continues for about three weeks. The entire metamorphosis of the blow-fly, therefore, requires from twenty to thirty days.

For breeding stock, fly eggs are transferred with the meat on which they are laid to a glass jar in a dark compartment. We have endeavored to breed larvae on various kinds of sterilized media, such as a chopped beef-calf brain medium, but anything other than native protein seems to yield flies with impaired vitality. When the larvae have become full-grown and have ceased feeding, the jars are placed in deep enamel containers, surrounded with sawdust, the cheesecloth covering of the jar removed, and the larvae allowed to migrate into the sawdust of their own accord. The inside of the enamel container is rimmed near the top with vaseline to restrain those individuals seized with the wanderlust. The sawdust is examined two or three times each week for the presence of pupae which are transferred to sterilized fly cages for hatching.

DISINFECTION OF MAGGOTS

Of course, the vast majority of the fly eggs are disinfected to procure sterile maggots for the surgeon's use. The description of the technique followed is taken from an article by Child and Roberts, which was published in the *New York State Journal of Medicine* for August 1, 1931.

> The main problem involved in preparing maggots suitable for clinical application is the use of a disinfecting procedure that is bactericidal without being insecticidal. . . . Accordingly, attention was turned toward the development of a procedure which would result in a minimum of bacterial contaminations and as nearly as possible a 100 per cent. hatch of the disinfected eggs. After extensive experimentation, the following technic was devised:
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> Fly eggs laid by the species enumerated above on either hog spleen or raw beef are removed by gently brushing off the clumps with the flat end of a tooth pick into a beaker of sterile distilled H_2O. The water should be at a temperature of 4° C. to prevent hatching of the eggs before disinfection takes place.
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> The apparatus for disinfection consists of a covered Gooch crucible attached to a filter tube by means of a thin-walled rubber tubing collar. The crucible and cover are sterilized separately, the crucible containing a small piece of fine mesh cheesecloth placed over the perforations. A short piece of ordinary rubber tubing is connected with the lower end of the filter tube which, with collar tubing attached, is immersed in 3 per cent. phenol when not in use. When the crucible, cover, and filter tube have been assembled, a pinch clamp is attached to the small-sized rubber tubing and the apparatus is ready for disinfection.
>
> Approximately 1100–1200 eggs are transferred to the cheesecloth layer in the crucible and are rinsed several times with sterile distilled H_2O (temperature 4° C.) to mechanically

remove bacteria. The pinch clamp is tightened and the egg clumps are thoroughly disintegrated by gently agitating them in 3–4 cc of a sodium hypochlorite solution yielding 0.5 per cent. available chlorine. Complete separation of the clumps is effected in ½–1 minute, and is important in that it makes the whole surface of each egg available to the action of the disinfecting agent.[1] After loosening the clamp, the eggs are thoroughly rinsed with sterile distilled H_2O to remove all traces of chlorine, the clamp is re-tightened, and a neutral solution containing 4 per cent. formaldehyde added to fill up the crucible. The eggs are exposed to this disinfectant for 3 minutes, then the clamp is loosened, and the eggs are rinsed a third time with sterile distilled H_2O. All agents in the above procedure are used at a temperature of 4° C.

As soon as most of the fluid has drained off, the piece of cheesecloth holding the disinfected eggs is transferred with sterile forceps to a 2 oz. bottle containing about 4 cc of a sterile semi-solid medium. The medium consists of 1 per cent. agar and desiccated liver. Experience has shown that poor hatching results if the cloth with eggs is dropped on the medium and therefore the bottom surface of the moist cloth is smoothed out so that it will adhere to the bottle wall.

The bottle is then placed in a hatching incubator (regulated for temperature, humidity, and ventilation with exclusion of light). Twenty-four hours later hatching is completed and the tiny maggots are tested for sterility by inoculating duplicate sets of fermentation broth tubes for detecting aerobes and deep meat tubes for detecting anaerobes.

After sterility-testing the bottle of maggots is returned to the incubator for another day of growth and then the bottle is transferred to the chill room (temperature 4° C.) to await the results of the sterility tests. Each bottle is held whenever possible for a 4-day reading on the sterility tests before it is shipped. On the average, the technic as described above results in 90 per cent. hatches free from bacterial contamination.[2] It must be remembered that each bottle is subjected to a 4-tube test and if only one of these tubes shows a contamination within 4 days after testing, it is not released. Moreover, all tests are actually held in the incubator 7 days as a check on the dependability of the sterilizing process. The hatch after disinfection varies between 90 and 100 per cent. of the hatch observed from non-disinfected eggs, the fertility of the eggs being comparable.

The method of shipment consists in packing the bottle of maggots next to a can of natural ice which is then surrounded by a 4–5 inch layer of pulverized cork as insulation between the chilled maggots and the walls of the carton. Since the ice in the package and the type of medium in the bottle both serve to retard the growth of the maggots while retaining their viability, they remain during transit at approximately the same 2-day stage of growth at which they are shipped, and therefore may be left in the wound 5 days unless unfavorably affected by the wound secretions or lack of food. Upon arrival, a bottle of maggots may be kept in an icebox at 4° C. for a few days before implantation if necessary, but this is obviously not desirable since the maggots are perishable and can not be stocked indefinitely. Such a procedure is certainly not feasible when a bottle remains more than two days in transportation.

ATTRIBUTES OF MAGGOT THERAPY

The question naturally arises in your minds, "What are the specific benefits of maggot therapy?" As expressed by Dr. Jacob Myers at the Illinois State Medical Society meeting, May 6, 1931, "the maggot treatment is advocated as an economical, efficient form of therapy which produces healing without draining sinuses in the shortest length of time, with the quickest return of function and the least retraction of the scar of any treatment in use at present." Maggot therapy succeeds in accomplishing what surgery has failed to do—namely, to eliminate bacteria and remove necrotic tissue. Bacteria probably are destroyed in several ways. One of the first effects to be noticed in the wound is a change from an acid to an alkaline reaction, presumably due to the vigorous production of ammonia which accompanies the liquefaction of meat by larvae. Dr. Baer believed that the alkalinity was partly responsible for the killing of microorganisms. Undoubtedly the maggots destroy bacteria mechanically by ingesting and digesting them. Possibly also a soluble substance is excreted which has a definite germicidal action. Certain it is that bacterial counts taken weekly show a marked progressive diminution in the number present. The end result of this germicidal action is that the maggots themselves can live in contact with the wound only a few hours after several implantations.

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[1] The chlorine dissolves the albuminous coating that holds the eggs together in clumps.

[2] Average now 95 per cent.

The removal of dead tissue by the maggots is almost phenomenal. This is assisted by the necessity of the blow-fly larva to liquefy its food, accomplished by the liberation of proteolytic enzymes. Thus the wound secretions are greatly increased, providing adequate drainage. Unlike the surgeon's knife or the chemical antiseptic, the maggots discriminate between the living and the dead tissue. Thus they seek out hidden pockets of infection which might otherwise perpetuate the disease. They separate dead particles of bone and feed on devitalized tissue until they arrive at the bleeding area. The efficient removal of all necrotic tissue allows the natural processes of repair to operate unhindered. Reddish compact granulation tissue grows over and attaches itself to the healthy bone and the wound fills up from the bottom, leaving the epithelium to merely grow over the surface. Thus the contour of the wound resembles the original shape of the part and disfiguration from deep pitting scars is relatively infrequent.

There is no purulent odor to the treatment and free pus is never apparent. A few patients have described a slight biting sensation possibly due to the proximity of the maggots to a sensory nerve. Another disadvantage reported has been an occasional rise of temperature on the third or fourth day following an implantation. This thermal response has been correlated with profuse discharges from the wound and is thought to be caused by insufficient drainage.

INDICATIONS FOR MAGGOT THERAPY

I have purposely chosen the title "Clinical Application of Blow-fly Larvae" instead of the "Larval Treatment of Chronic Osteomyelitis," because I believe that maggot therapy is applicable to many other suppurating and sloughing types of wounds. It can not be denied that the case is proven only for osteomyelitis, but evidence is rapidly accumulating to show its effectiveness in other diseased conditions. Based on a series of seven tuberculous cases, Dr. Baer concluded as follows, "In open tuberculous abscesses, with or without secondary infection, wide exposure followed by maggot treatment has proved surprisingly effective." Not only are tuberculous lesions receiving attention but also chronic leg ulcers and even carbuncles are being treated in several clinics with most gratifying results.

With the growing realization that a powerful ally is now available to the host in its struggle against the parasite (bacterium), I firmly believe that maggot therapy will find a wider and wider field of usefulness.

A SIMPLIFIED CALENDAR

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THE inadequacies of our present calendar need no comment. Decisive steps are being taken toward its revision, by the League of Nations and by influential organizations in many countries. The change to a new calendar, more simple and useful, is inevitable. When it comes, it is of the utmost importance that the new device should be as perfect as it can be made. Absolute simplicity is unattainable, because day and year, week and year, lunar month and year, are incommensurable periods of time. By simple adjustments and conventions, however, the difficulty can be overcome and a close approximation to perfection and simplicity attained.

Of the two alternative plans now most in favor, each has avoidable imperfections. One, the thirteen-month plan, has the very great advantage of fixed association between week-day and month-date, since every month begins on Sunday and has 28 days. But it does not adapt itself easily to an even division of the year into quarters, which is desirable for two reasons: the astronomical fact that the seasons do so arrange themselves; and the common commercial practise of conducting various businesses with reference to quarterly periods. The other, known variously as the Swiss Calendar, the World Calendar, or the New Era Calendar, has the advantage of an even division of the year into quarters, two months in each quarter having 30 days and the other 31. But it involves the disadvantageous retention of a disparity between week-day and month-date, although to a much less confusing degree than the present calendar. Both systems propose to fill out the year by insertion of an intercalary "year-day" each year, belonging to no month, and of a similar intercalary "leap-day" in leap years. The New Era proposal[1] seeks to meet certain religious objections by calling the "year-days" in successive years by successive week-day names, and the "leap-days" in successive four-year periods by their own successive week-day names, thus adding a "year-week" to the other weeks once in seven years, and a further "leap-week" once in twenty-eight years. This would involve the peculiar situation of having "weeks" whose successive days are a year or four years apart, and of inserting between Sunday, December 31, and Monday, January 1, every year, a week-day called Tuesday, or Friday, or any other week-day name in its turn.

Probably one reason why calendar reform has not met with more rapid and enthusiastically-greeted progress has been the conflict of the two systems proposed, and the fact that each falls short of a completely acceptable system. A device possessing the advantages of both and the imperfections of neither ought to have a much better chance of early adoption. Such a device is entirely feasible, and involves changes that are hardly more numerous and radical than those necessitated by either of the others. Its individual features, of course, with perhaps one or two exceptions, have been thought of by others already. As a whole, it more nearly resembles a scheme suggested in 1910 by T. C. Chamberlin,[2] than any other; but in some important ways I regard it as better. As a total assembly, so far as I am aware, it is new, and it seems to me appropriate that it should be baptized with the name of the city in which the idea of it was born, and be known, therefore, as the Providence Simplified Calendar. Should it meet with sufficient support to secure eventual adoption, just as dates under the Julian calendar are called Old Style (O. S.), and those under the Gregorian calendar are called New Style (N. S.), so under this one they could be called Simplified (or Scientific) Style (S. S.).

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[1] Howard C. Warren, *Science*, n. s., 47: 375–377, 1918; and THE SCIENTIFIC MONTHLY, 33, 440–442, 1931.

[2] *Science*, n. s., 32, page 757, 1910.

The largest attainable perfection, it would seem, ought to include the following features: (1) The calendar for all years to be the same, except for the regular introduction of a leap-day at intervals as at present. (2) Beginning of year to be replaced where it astronomically belongs, at the winter solstice. (3) Year divisible into even quarters, both for astronomical and for business reasons. (4) Retention of twelve months, each of exactly four weeks and of exactly 28 days. (5) Inclusion of an exactly even number of weeks in the year.

At first sight, this combination seems to be impossible. It is feasible, nevertheless, if we introduce three conventions against which no strong reasons can be alleged, in addition to the already accepted convention of leap-day. First, let each quarter begin with an intercalary or seasonal week, belonging to no month. Second, let New Year Day, and Leap Day when it occurs, also belong to no month, but be regarded as zero-day of the week which follows. Third, let each of these intercalary days be called Sunday, to be followed by Sunday the first of the week. Thus there would occur, once each year and twice in leap years, a Double Sunday. This Sunday would be astronomically two 24-hour days. But, for religious and legal purposes, it could be taken symbolically as one 48-hour day. Such a convention would emphasize the importance of the Sabbath rather than interrupt its regular recurrence, and would give the year, in the only way possible, an exactly even number of weeks. We are accustomed already to the convention of a 23-hour day and a 25-hour day each year, involved in the adoption of the daylight saving plan. It would be quite as easy to adapt ourselves to a 48-hour day once or twice a year.

Most of the other "simplified calendars" that have been proposed retain January 1 as New Year Day, and hence insert the extra Year-Day as the last one of the old year. There are no very good reasons for doing this, when so much more of meaning will attach to the day if treated in the manner that I suggest. Historically, the beginning of the year has moved around throughout the entire calendar. It is only accident which has placed it in its exact present position. But there is a significance, inexactly applied, that has determined its place. It represents the occurrence of the winter solstice, and has become shifted from the day when that event occurs. At the true solstice, the sun has reached its farthest position south of the equator and begins to return, with promise of new warmth and new growth, to northern latitudes. From far prehistoric times men have made this event an occasion for celebration and rejoicing.

We ought to restore this immemorial meaning of "New Year," which men in northern climes will never outgrow, by placing it at what we know to be its exact and proper date, as nearly as it can be done. Because of the circumstances which necessitate leap-years, the actual solstice falls sometimes on December twenty-first, sometimes on the twenty-second. Of these two days between which we have to choose, the earlier of them, December twenty-first, seems the more appropriate. It has the added great advantage of leaving two full business days between the Double Sunday and Christmas day, whereas the choice of the twenty-second would leave but one. This change will involve, it is true, dropping eleven days out of the year when the new system goes into effect. But this is a simple device which has been applied before without any disastrous effect: in 1582 in Catholic countries, in 1752 in England and America.[3] The best time to do it would

[3] Gregory XIII, "perceiving that the measure was likely to confer a great *éclat* on his pontificate, undertook the long desired reformation" (Encyc. Brit., ed. 11). The change went

be when December 21 falls upon a Saturday. This will occur in 1935, next in 1940, and again in 1946. In the first year of its adoption the day would be called Saturday, New Year Day, 1936, or 1941, or 1947. Thereafter, it would always be Sunday, New Year Day of a new year, to be followed by Sunday, Winterweek 1, and a week later by Sunday, January 1, which would no longer have any "new year" significance. Christmas, another symbol of birth and of beginning of new and better things, would come appropriately after New Year Day, falling always conveniently on Wednesday, the fourth day of New Year Week, or Christmas Week, or Winterweek, or whatever it may be called. This would leave it in exactly the same position in the astronomical year which it now occupies—four days after the solstice.

The year begins, then, at the winter solstice, with New Year Day, always a zero-Sunday. After it follows Winterweek, beginning with Sunday the first and ending with Saturday the seventh. Then follow three months, January, February and March, each beginning with Sunday the first and ending with Saturday the twenty-eighth. There is always exact fixity between date and week-day. Next comes Springweek, or Easter Week, or whatever it may be named. Its first day, Sunday, will correspond as nearly as possible to the time of the vernal equinox. It will be followed by three months of 28 days each, named as at present. Next, when necessary, comes Sunday, Leap Day, followed by Sunday, Summerweek 1, at summer solstice as nearly as possible. Three months of 28 days each complete the third quarter of the year. The fourth quarter begins, at autumnal equinox, with Sunday, Autumnweek 1, and this week is followed by the last three months of the year, again with 28 days each. Counting Double Sunday as legally and symbolically one day, each quarter contains exactly 91 days. The year ends on the present December 20, which becomes the new Saturday, December 28. By means of the convention of Double Sunday, it contains exactly 52 weeks; and by means of the four inserted seasonal weeks, it is divisible into four exactly even quarters. It has the inestimable advantage of having one calendar serve for every year, and of having month-date or week-date correspond to the same week-day name in every month of every year.

The only disadvantage of this proposal is that it interferes slightly with the familiar conception of the month. But the month, founded on lunar periods which can not be reconciled conveniently with solar periods, must suffer some change in any revised calendar. Either we must insert a new one, or we must have them unequal in length and incommensurable with the week, or we must adopt the device of four inserted separate weeks. For purposes of industrial, financial, commercial and many other established practises, the equal quarters of the year are more important than the particular arrangement of months. Wages, salaries, dividends, interest and other transactions are based much more often on unit-periods of hour, day, week, quarter, half-year and year, than they are upon months. Any practise now adjusted to months will have to be revised to fit any new calendar, and can be adjusted to this one as readily as it could to any other. In fact, it would be easier to make calculations dealing with these new months and quarter-months than to continue to make use of our present variable calendars. Monthly bills and wage schedules, for instance, perhaps may be adjusted to cover five weeks in the first third of each quarter, and four weeks in the others. There would be no difficulty attending the adoption of any other manner of dividing the quarter into thirds or other approximate monthly periods that might

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into effect in 1582 in Rome, parts of Italy, Spain, Portugal, France; in 1583 in Catholic states of Germany; in 1700 in Protestant states of Germany; in 1752 in England, where September 3 became September 14, and new year was changed from March 25 to January 1.

suit individual convenience, and a year or two of use would lead without inconvenience to substitutions that would smooth away all difficulties.

The names which I have proposed tentatively for the inserted weeks are Winterweek, Springweek, Summerweek, Autumnweek. They are words of about the same length as the names of most of our months, and each is abbreviated readily by use of its first three letters. They do not apply, of course, so appropriately to seasons south of the equator. Perhaps better names may be devised; or perhaps these are best, with the consequence that southern peoples must accept conventions which have their origin in northern temperate zones.

The new month-dates will differ from the old ones by an average of only five days, with extreme difference of two days at the least and eight days at the most. The new Sunday, January 1, will be the old December 29, the old January 1 becomes the new Wednesday, January 4. One great advantage of this, as of the other proposed new calendars, will be the fixed connection between holidays and anniversaries, and the days of the week. The fixation of the day of Easter is almost sure to be decided upon by religious bodies before long. Some other American anniversaries would be as follows, if they are to occur on new dates corresponding to their old ones: February 12 (Lincoln): Wednesday, February 18; February 22 (Washington): Saturday, February 28; March 4 (Inauguration): Tuesday, March 10; May 30 (Decoration): Friday, June 6; July 4 (Independence): Friday, July 6; first Monday September (Labor): Monday, September 9; October 12 (Columbus): Sunday, October 15; first Tuesday November (Election): Tuesday, November 10; November 11 (Armistice): Tuesday, November 17; last Thursday November (Thanksgiving): Thursday, December 5; December 25 (Christmas): Wednesday, Winterweek 4. The academic year for educational institutions will be greatly simplified and stabilized. Brown University, for instance, if it should conform to the nearest present average dates, would begin its academic year always on Wednesday, Autumnweek 4, and hold Commencement on Monday, June 23. It would be easy, however, to make readjustments, if a more efficient distribution of holiday periods should make them desirable.

Conservative clinging to established customs is one difficulty in the way of the introduction of any kind of change. This must yield when confronted with the promise of large increase in efficiency and satisfaction that is sure to follow the change. Religious prejudice, probably, is the only other serious difficulty to be met. A new universal calendar must come as near as it can to satisfying the demands of all religious bodies, non-Christian as well as Christian. Any of them which maintain calendars different from ours, as some of them do, can adjust themselves to the revised calendar as easily as they could to the one in present use. Any religious belief that the week of seven days, or the lunar month, is divinely ordained, is confronted with the indubitable fact that the year is just as surely a divinely appointed period, and that it is incommensurable with day, week or month. If the Divine Being is responsible for any of these things, it is evident that he has instituted conflicting divine schemes of time division, and has left it to the ingenuity of man to reconcile them as wisely as he can according to his own needs. He must make adjustments of some kind, and always has. It would seem that the adjustments suggested in this paper are the simplest and most logical that could be devised, combining the advantages of the other proposed schemes with the disadvantages of neither of them. The important thing, however, is to get one of the three adopted, whichever one of them can secure practically unanimous endorsement.

ENVIRONMENT AND HEREDITY

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ENVIRONMENT is what surrounds anything. On the earth it is made up of psysical things, such as wind, waves, water, rocks, and oxygen, and of organisms, such as food plants and animals, lurking enemies, and astute competitors. For man and for some other animals there is a social enviroment, which consists of such things as the boys at the office, grammar, golf, bow ties, bridge games, and ladies' aid societies. Man has reared culture as the fairest flower in his time-binding garden of civilization. Man not only struggles and lives in his environment, but he aspires to live in the best possible way—to be a cultured gentleman.

Environment continually changes. Daily and annually there are minor or extreme fluctuations in humidity, wind, temperature, the stock market, total sales, and religious converts. At times there are major changes in environment. Glacial epochs cool the earth and change the volumes of oceans; great upheavals or depressions of the earth's crust make mountain ranges or new oceans; empires change to republics. During glacial times there were reindeer in Italy. The pantaloons and stocks that grandfather wore during civil war days are now ridiculous and archaic. The outstanding quality of environment is change—fluctuation, mutation, modification, and transformation.

In environment lives the organism—plant or animal. This organism has certain well known qualities, but when one tries to define it in critical scientific terms, many difficulties are encountered. An organism has metabolism; the power of growth, repair, and reproduction; specificity; manifoldness, and peculiar organization. Yet it is made of matter and its usual activities are associated with well known chemical and physical processes. Perhaps it is nothing but matter and energy; perhaps it has in addition to these some vital spark which keeps it organized and harmoniously living. All that science has been able to say about the organism is that it is a "coordinated, self-perpetuating, system of activities." Its primary quality is continual activity. Like environment it is always changing.

An organism never exists for an instant without its environment. Furthermore, every organism is adapted to its environment—it fits. A fish belongs in water; a bird, in air; a snake, on its belly on the surface of the earth; a Negro in the tropics; an Eskimo in arctic regions. An ever-changing organism thus lives in an always-varying environment and must continually be adapted to it. This is a complex and trying situation which may well discourage any organism which is earnestly struggling to survive. It is mitigated somewhat by the fact that every organism has certain powers of adjustment, so that it can change from day to day or from year to year to keep pace with minor changes in environment. A man grows callouses on his hands if he spades; a tick can live for four years without food. Some animals and plants have remarkable powers of adjustment or of toleration for variations in environment. Such types usually have wide geographic ranges and often live in a variety of habitats. Organisms with narrow ranges of adjustment are correspondingly limited. A house fly lives in many parts of the earth and subsists on many foods; the honey bee depends on certain types of flowers and can not thrive without them.

Heredity is jealous of change. Its mechanisms, as they are at present known to science, permit animals to mix their qualities in a nearly endless variety of combinations, but they seldom or never permit species to change. The transfer of hereditary qualities from parent to offspring through particular chromosomes and genes is well known. Recently there have been several very illuminating discoveries in this particular field. But what causes animals to vary, to change their limits of toleration and adjustment, is still a mystery. Scientific experiments which have been intended to transform one species into another on the whole have been quite negative. A species can be selected so that potential characters which it already has may be emphasized, but experiments which have extended over a limited range of time have not resulted in new species. Osborn[1] says, "This incredibly slow rate exposes the futility of modern experimental research which would produce a new character in a single year or in a few seconds."

Evolution is thus left by science between two horns of a dilemma. Animals certainly have changed and have been transformed into new species. But when Nature's favorite child tries to produce species for himself, Heredity blocks his progress into the promised Land of Discovery, and ever turns him back into the fields of Adjustment, Hybridization, Mendelism, and other long-tilled areas. But, if species have evolved out of preexisting species in the past, they are probably doing it to-day. Perhaps if man can carry his cumulative scientific knowledge, his experiments and his discoveries on for another million or billion of years, he may discover the secret of evolution. Perhaps some fortunate genius may discover such secrets during the span of his life. Until the time comes when there is scientific evidence on which to base general laws there will be controversy. The advocates of either heredity or environment as the primary factor in evolution will go on speculating and asserting. Every mother believes that Environment is a magician who can make the son of a drunken ne'er-do-well into a competent, great, and noble personality. Every father knows in his secret heart that he is more or less of a failure, but lives in the hope that his boy may become a superman if he gives him golden opportunity. This is sentiment, and perhaps also a grain of vanity, for the parent excuses himself to himself by laying the burden of failure on lack of opportunity. Science is judicial and, though generally kindly in spirit and open minded, she hates Sentiment. Her favorite children are Truth and Evidence. She tolerates Theories only as strictly temporary incumbents of positions that later are to be filled by established Natural Laws.

It must be admitted that at present scientific evidence gives little support to environment as a primary cause for the production of new species. In the pamphlet[2] which gives brief discussions of the exhibits which were recently shown in connection with annual meeting of the Carnegie Institution, there is evidence on this point. Dr. H. M. Hall has been working many years on a genus of plants to discover whether what have been called species are the products of adjustment to present environmental conditions or whether they are due to heredity. He says, "The investigations exhibited are not designed to give a conclusive answer to this very debatable question, but thus far no changes have been induced by environmental conditions which have the appearance of becoming hereditary." Dr. H. E. Crampton, who has made extensive studies of land snails of the genus Partula on the islands of the Pacific Ocean, remarks, "The variations among species of this genus and the variations within any single species are to be interpreted in terms of innate or congenital factors, and the circumstances of 'environment' are not in any way causal with reference to the characteristic qualities of a localized race, variety or species." Dr. A. M. Banta reports a case he actually observed where the offspring of one crustacean survived unusually high temperatures. It is noticeable that he gives no suggestion as to how the new limits of toleration were acquired; he is too scientific. He is satisfied merely to state that he did observe the origin of a new range of toleration in a species. Dr. E. C. Case, who has published two great works on the origin of tetrapods in relation to climate, concludes that land vertebrates originated when the environment was quite monotonous for a very long period.

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[1] H. F. Osborn, "New Concept of Evolution Based upon Researches on the Titanotheres and the Proboscidians," *Science*, 74: 557–559, 1931.

[2] E. C. MacDowell, "Exhibition Representing Research Activities." Carnegie Institution, Washington, 1–32, 1931.

Heredity gives an animal its native ability. Environment gives an animal opportunity. A college education will not transform a fool into a wise man, but it should give a man opportunity to develop what native ability he has. There is little evidence that any animal can change its inherited abilities during its life. If a potentially great man was shut up in a dungeon and fed through a hole in the door, he could never get experience and education enough to develop. He would probably never write poetry, build railroads, or lead armies. He could not develop completely without his environmental opportunities. So it is with all animals.

The writer has been privileged for a number of years to study the migrations of animals from the ocean into fresh-water and land habitats. These migrations have taken place during the past and are progressing in many parts of the earth at the present time. Animals have left the stable, dependable ocean in order to take up a precarious, uncertain life on land. Animals which are forced to live in a changeful environment, continually seek to attain some degree of stability. In going from ocean to land animals have escaped certain dangers and competitions, and incidentally they have developed mechanisms which enable them to live in the extremely variable land habitats by attaining more and more internal stability. Land animals have effective, and often elaborate, mechanisms for conserving water, regulating temperature, maintaining internal fluids at optimum concentrations, respiration in air, reproduction, locomotion and sensation in air.

In connection with the study of landward migrations I have often been impressed with the idea that new species perhaps arose when there was a segregation of certain types into particular habitats in order to avoid competition. The four common species of hermit crabs at Dry Tortugas are arranged in definite zones and their gills decrease in number toward the land. Those that live in the ocean have 26 gills; the species which is established on the reefs at high tide mark has 18 gills; and the land hermit crab has 14 gills. On the mud flats at the mouth of the mighty Menam in Siam there are three species of gobies which hunt together on the beaches. These land fishes show little or no arrangement into zones, but a careful study of their habits showed that they were quite definitely segregated, so that they avoided competition. The largest species subsisted largely on crabs and large insects and had a short intestine; the medium-sized species ate little but algae and had a long intestine; the smallest species ate ants and other small animals and had a short intestine. Even the parasites of these three gobies were strikingly different. Though the three species lived together continually, they were not competing. After encountering many such instances I have tentatively come to the conclusion that perhaps a new species begins when a group of animals is able to invade an unoccupied niche in nature, and thus avoids competition. Such a group probably soon attains some degree of stability in relation to certain environmental factors and gradually makes adjustments which make it more and more closely adapted to existing conditions. What causes such an incipient species to change its habits and its limits of toleration is of course unknown. Evolution may be more or less due to isolation (Wagner), orthogenesis (Eimer), natural selection (Darwin), the transmission of acquired characters (Lamarck), hybridization (Johanssen), aristogenesis (Osborn), accumulated mutations (Morgan), or other things. Osborn[1] recently published a list of the principles of evolution as shown by paleontology. Such "laws" of evolution are not yet firmly established; they are still in the theoretical state. This is the challenge and the inspiration for the young biologists.

It may seem that this attempt to set forth the present status of environment and heredity in relation to evolution involves a rather hopeless philosophy for application to every-day life. There seems to be little doubt that any organism, man included, is born with a certain equipment in the way of capacity or ability. Environment may give the organism the opportunity to bring this to the greatest possible fruition. Every man is born with certain aptitudes for mathematics, music, business, art, politics, mechanics, or what not. Environment as it exists in climate, food, dwelling, home life, school, and state should give him unlimited opportunity to develop what he has. It is the obligation of civilization to make environment such that each individual has opportunity to develop the best personality that his given abilities permit.

To a scientist this outlook is inspiring. Present day biology says, "Be what you are. Waste no time in trying to make yourself what you are not, and do not try to convince the world that you are something different than what you are. Take your given capacities and make the best possible; struggle and improve. Throughout life you must change—adjust as environment changes. Perhaps with your unique intellect you can even change your environment to suit your particular abilities. Environment is opportunity."

I find the great thing in this world is not so much where we stand as in what direction we are moving. To reach the port of heaven we must sail, sometimes with the wind and sometimes against it,—but we must sail, and not drift, nor lie at anchor.—*Oliver Wendell Holmes.*

POPULAR USAGE OF THE TERMS "INSTINCT" AND "INSTINCTIVE"

By Dr. RICHARD STEPHEN UHRBROCK

PSYCHOLOGICAL terminology is being used with increasing frequency by the newspaper writer, the magazine contributor and the novelist. If we are to judge by examples that have appeared in leading publications during the past year, any phenomenon of behavior that tends to exhibit even a minor degree of stability sooner or later will be referred to as "instinctive."

Contemporary writers of all classes make frequent use of the words "instinct" and "instinctive," but, with very few exceptions, they use them so loosely that they have almost spoilt them for scientific purposes. On the one hand, the adjective "instinctive" is commonly applied to every human action that is performed without deliberate reflexion; on the other hand, the actions of animals are popularly attributed to instinct, and in this connexion instinct is vaguely conceived as a mysterious faculty, utterly different in nature from any human faculty, which Providence has given to the brutes because the higher faculty of reason has been denied them. Hundreds of passages might be quoted from contemporary authors, even some of considerable philosophical culture, to illustrate how these two words are used with a minimum of meaning, generally with the effect of disguising from the writer the obscurity and incoherence of his thought.[1]

The following examples of the popular usage of the terms "instinct" and "instinctive" have been culled from a variety of sources. Some of the writers who have contributed to this list are famous wherever English is read and spoken. The identity of others is concealed, owing to the fact that it is the policy of American newspaper editors not to sign their articles.

(1) The officer knew instinctively that the man was unfamiliar with the gear shifts in that particular make of car.

(2) This ability must be linked with sound business judgment, promotional instinct and a sense for news.

(3) Henry P. Davison, who at forty was a partner in J. P. Morgan & Company, was not born to riches, but he must have been born with a natural instinct for banking.

(4) Instinctively he had dropped his fingers towards his right coat pocket, but he thought better of that maneuver and slightly raised his hands.

(5) Hoppe is probably without a rival in his instinctive knowledge of the angles of a billiard table.

(6) Versed in his youth in the use of the "lazo" and the "boleadoras" than the pen, I think his love of nature set him on to write instinctively, just as a gaucho child, putting its little naked toe upon the horse's knee, climbs up and rides because he is compelled to ride or remain a maimed and crippled animal, traveling the plains on foot.

(7) Yes, almost a commercial instinct.

(8) Suddenly a camera man snapped its shutter in the ex-Premier's face and the commercial instinct of America was satisfied.

(9) Lacking the Saxon training for self-government and the Saxon instinct for individual rights, they have not felt sorely the grievances under which the English speaking colonies smarted.

(10) Was the West African instinct getting the upper hand in him over the Christian gentleman?

(11) This was even more to my taste, for I had an instinctive liking for Frenchmen, and was anxious to see as much of them as possible.

(12) Their business instincts usually directed industrial endeavor into the most productive channels.

(13) But the story has fed, too, on the incurable snob instinct in the heart of all of us.

(14) Now ordinarily Katherine would no more have bent her ear to this dialogue than she would have peeped into another woman's portfolio; but a catlike instinct glued her to the receiver.

(15) The instinct of benevolence appears to be innate in every kindly nature.

(16) So that if you saw a piece of work finished in gilt-edged order—whether it was a job of leadership, a book, washing dishes, or a sewer cleaned, done *right* and shipshape "and then some," you would instinctively say: "There's been a Princeton man on this job. That's the *Princeton way of doing things.*"

(17) He is a second generation Puritan who satisfies his reformer's instinct by booming Zenith City, and his moral prejudices by being a good boy most of the time and distrusting the bad ones.

(18) Impulsive, politically iracund, often the victim of his vocabulary and his instinct for salient phrases and marrowy nicknames, he sometimes wounded beyond his intention.

(19) On hearing the last word, Dona Ana shivered and instinctively turned to look at the picture in which Roberts had been portrayed dying in the gloomy desert.

(20) With the instinct of a Commissioner of Accounts still upon him, Mr. Fosdick inquires whether we have liquid "spiritual assets" to counterbalance the new forces which he seems to regard as potential liabilities.

(21) As in the case of several other young poets of this war-moment, too much importance has been attached to a pleasant and congenial instinct for making Rhymes.

(22) Yet I have no doubt that, with his instinctive courtesy, he divined the wishes of the family in regard to the newcomer and was, therefore, predisposed in his favour.

(23) As I looked at them, I instinctively summoned to my side the radiant shade of Aurea, for indeed she had seemed made of gold —gold and water lilies.

(24) Most novices have a misguided but unerring instinct for *hard* pipes, and this way trouble lies.

(25) My first instinct is to reach for money.

(26) One morning, as they tell it, depending upon her instinct of time, she rose without consulting her clock (which in fact had stopped).

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[1] William McDougall, "An Introduction to Social Psychology," London, Methuen and Co., Ltd., pp. 20–21, 1914.

(27) In choosing a confessed apostleship of Bolshevism as the point of attack, Mr. Gompers evinced his instinct for the jugular vein.

(28) She was a lady by instinct, in short, and Kate's father was—well, otherwise.

(29) Aunt Ella's atavistic instincts had demanded a gas fire in the asbestos hearth as part of the ceremonial welcome.

(30) There is a type of reader who will object to the publication of such a book, claiming that it is merely a text-book based on the "direct method," for those who are cursed from birth with criminal instincts.

(31) For of course it meant only that she felt a woman's instinctive rebellion against all such philosophies.

(32) Instinctively his face resumed its old, mocking mask; there was no other way in which he could keep a hold on self-control.

(33) . . . but partly it was due to that instinct for ordered routine, which in a reputable sphere of endeavor would have made this man rather conventional and methodical in his personal habits.

(34) Just then a murmur came from the dying woman within, and nurse and doctor, moved by professional instinct, stepped softly back to the bedside.

(35) But the child had an instinctive aversion to all savages, or possibly the feeling was derived from her mother.

(36) Why is it, we thought, that one instinctively waves to unknown travellers who pass on train or ship?

(37) They snout out the superficial night life of the city with the unerring instinct of all small towners for the perverse and the vicious.

(38) Vernon had not gone far before he regretted his instinct for short cuts.

(39) John Creddy saw the shadow on her face, the unintentional dilation of her delicate nostrils, the faint puckering at the corner of her lips, and knew with a negro's quick instinct of face reading what it all meant.

(40) For, after all, humanity has an uncanny instinct to avoid truth as long as it can.

(41) I have seen a few cases, and only a few, where the style and the matter were so characteristic that all my literary instincts told me that it was the man himself.

(42) It was Mr. G. K. Chesterton who noted that the American man instinctively removes his hat in an office elevator, as a kind of subconscious tribute to his totems of machinery and commerce.

(43) The rich are instinctively crying "Let us eat and drink; for tomorrow we die," and the poor, "How long, O Lord, how long."

(44) The instinct of patriotism, loyalty and altruism can be stimulated and educated.

(45) The instinct of the race regards intercourse between unmarried persons as immoral and anti-social.

In discussing the word "instinct," Dashiell has said:

> At one time the term has been used with reference to a pattern of activity (*e.g.*, walking, manipulation), at another, with reference to the motivation of activity (*e.g.*, curiosity, pugnacity, parental love), and perhaps most frequently, in a way both descriptive and explanatory. The classic notion of "instincts" as God-given faculties mysteriously implanted in animals to guide them aright has given place to inquiries of more scientific types; but contemporary discussions are remarkable for the amount of misunderstanding and confusion traceable to the vagueness of this one term. Bernard found in the literature 849 separate types of "instinct," which he was able to condense to 325 irreducible ones. As Bohn puts it, "Qu'est-ce que l'instinct? Un mot"; or even as Condillac says, "L'instinct n'est rien."[2]

Now that the psychologists are debating the use of the terms "instinct" and "instinctive," the popular writers have adopted them to describe habits and habitual reactions. They have not been concerned, however, with any questions as to whether the responses under discussion exist at birth, or soon after; whether they are universal in appearance and whether they appear without opportunity to learn, as suggested by Gates.[3] Neither do they apply Dashiell's two queries concerning the nature of the act itself. "Does the activity in question natively *fall into some definite and recognizable pattern?* And further, is it natively *excited into activity by some identifiable particular type of stimulus or situation?*"[4]

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[2] John Frederick Dashiell, "Fundamentals of Objective Psychology," Boston, Houghton, Mifflin Co., p. 183, 1928.

[3] Arthur I. Gates, "Elementary Psychology," New York, The Macmillan Company, pp. 115–116, 1928.

[4] John Frederick Dashiell, "Fundamentals of Objective Psychology," Boston, Houghton, Mifflin Co., p. 185, 1928.

SCIENCE SERVICE RADIO TALKS

PRESENTED OVER THE COLUMBIA BROADCASTING SYSTEM

THE SURVEY OF THE CONTINENTAL SHELF

By Commander G. T. RUDE

CHIEF OF THE DIVISION OF HYDROGRAPHY AND TOPOGRAPHY, U. S. COAST AND GEODETIC SURVEY

WRITINGS of the ancients, even back to Noah's memorable cruise, contain warnings of the dangers of the sea. The Psalmist wrote of the perils which beset those "who go down to the sea in ships," having reference undoubtedly to the perils of the surface of the sea—of the wave and of the storm and their devastating effect on the small craft of the ancients. The bottom of the sea, however, with its hidden rocks and shoals holds more of menace to the giant vessel of to-day than does the storm. Yet even these are being rendered harmless before the advance of science. The scientist is making the bottom of the ocean echo its whereabouts back to him afloat on its surface, and accurate marine surveys based on the scientific principles involved are robbing the sea of its hidden mysteries.

Early in the history of this country, President Jefferson, recognizing the need for accurate surveys of our coast, inaugurated the organic act passed by the Congress in 1807 for the establishment of the Coast Survey, the oldest scientific bureau in the United States Government.

The intervening century has seen a marked increase in its activities and today its operations extend half way around the world and from the Arctic Ocean to the Equator—from the Philippine Archipelago to Porto Rico and from Alaska to the Caribbean Sea.

The bureau's work is not spectacular and therefore draws little public attention. Many of you probably are not acquainted with its operations. The results, however, exemplified in the nautical charts, open our ports to the armadas of commerce, affecting directly or indirectly the well-being of every citizen. They guide the mariner through safe lanes and warn him of unseen rocks and shoals that might bring him to grief.

The brevity of this history is indicative of the brief manner in which it will be possible, in the time allotted, merely to touch upon one of the many varied activities of this bureau—the survey of the continental shelf.

It may be well first to sketch briefly a description of the continental shelf before describing its survey and the unique methods employed. It may appear to us when visiting the beaches that the edge of the continent is represented by the shore where sea and land meet. Farther seaward, however, extends a gently sloping submerged plain, over which the water gradually increases in depth to six hundred feet at the actual edge of the continent where it begins to dip sharply to ocean depths. This submerged area is known as the continental shelf, and its average width along the coast of the United States is about sixty-five miles. Its outer edge lies only ten miles offshore at Palm Beach. This distance, however, gradually increases northward, and in the vicinity of New York, it is one hundred miles, and off Nantucket Island, two hundred miles.

In general, this plain is composed of material washed down from the land and is of a gently rolling character, but that part known as Georges Bank, extending as a huge tongue two hundred miles off the coast of Nantucket Island, has the characteristics of a terminal moraine, with its shoals and hummocks of glacial material.

For the probable formation of this offshore bank, we must go back to a period before the dawn of history, except as written in the rocks by the hand of nature. Geologists have read this rock-hewn history written by nature's forces; they tell us that during the Glacial Period, or the Great Ice Age, the northeastern states were covered by great ice sheets extending as far south as the State of New Jersey and offshore to the outer edge of Georges Bank. As this great ice mass ploughed its way southward and finally melted with the coming of a warmer geologic period, it left its mass of débris gathered in its slow march to the sea. To this is attributed the hummocks, characteristic of the shoal area comprising this offshore bank.

I have described in some detail that part of the continental shelf known as Georges Bank, because the Coast and Geodetic Survey is now engaged on a survey of that area, which is twice the size of the state of Massachusetts. This survey was started in the spring of 1930 and will be completed in the fall of 1932.

The purpose of this project is to modernize the nautical chart, through the resources and methods of modern science, to meet requirements of the navigator of the large vessel of to-day, equipped with the efficient navigational appliances now available. The navigator of the past was compelled at times to grope his way with only the knowledge that he had a sufficient depth of water under his vessel. The nautical chart of to-day, however, must supply him a wealth of detail of submarine valley, plateau or mountain range, for with his "echo sounding" apparatus he has the means of obtaining, at full speed, a continuous record of these submerged features under his ship. He is thus furnished a useful aid in the determination of his position in thick weather, when celestial bodies are not available for that purpose.

An interesting result of this survey was the discovery of a submarine valley extending back into the continental shelf on the southeastern edge of the bank. It was discovered by the Survey ship *Oceanographer,* formerly the yacht *Corsair II,* a gift to the government from Mr. J. Pierpont Morgan. As a tribute to this trim vessel, now engaged in charting the ocean she sailed for many years as a pleasure craft, the valley has been named *Corsair Gorge.*

This valley, probably a great gash left by a giant landslide of the glacial material, is two miles wide, eight miles long and eighteen hundred feet deep. This material, having slipped from its insecure hold onto the side of the continent, probably now lies at a depth of six thousand feet just off the edge of the bank. The valley is adjacent to the northern steamer tracks between New York and European ports and with their echo-sounding apparatus furnishes navigators of the liners an excellent additional aid in finding their positions during the thick weather so prevalent in this region.

This echo-sounding device, called a fathometer, is also used by the marine surveyor for determining the depths which appear on the chart in their correct positions relative to each other and to the continent, for the nautical chart is a miniature representation, on a plane surface, of the oceans and the adjoining land masses. The fathometer, briefly, is composed first of an electrically-controlled hammer which, upon striking against the inner steel plate of the vessel's bottom, generates sound waves in the sea water. These vibratory waves travel to the ocean's floor, from which they are reflected as an echo back to the ship and are received by a hydrophone, or sensitive mechanical "ear" fastened against the ship's bottom, the second unit of the fathometer.

After receipt in the hydrophone, the vibrations are amplified and passed on through electric wires to the indicator, the third unit of the fathometer, in the pilot house. This indicator automatically translates into depth the time required for the sound to travel to the ocean floor and to return as an echo, and also indicates this depth in fathoms by a flash of light on a graduated dial. By means of this sensitive instrument, a vessel at full speed obtains a sounding every few seconds, even in great depths.

Before the world war a deep sounding in the ocean was obtained by reeling out over a measuring sheave piano wire to which was attached a spherical shot, weighing about a hundred pounds. Over an hour was required to take a sounding of 20,000 feet. A sounding in this same depth can to-day be made with the fathometer in exactly eight and one third seconds.

The scientist, having developed this supersensitive instrument for obtaining measurements of ocean depths, has also devised a means of locating these soundings because, to be of any value in the construction of a nautical chart, their positions must be determined relative to the continent as well as to each other. This method for accurately locating soundings, known as radio acoustic ranging, is based upon research work during the world war for detecting hostile submarines. Like the fathometer, this operation, too, is dependent upon a knowledge of the velocity of sound in sea water, which has been determined to be a little less than five thousand feet per second.

In the case of this particular survey of Georges Bank, a number of buoys are anchored along the ridge of the bank in about two hundred feet of water so as to form a chain of triangles with sides ten to fifteen miles long, a buoy at the vertex of each triangle. A station ship is anchored near a buoy at one end of this chain, and by means of a series of observations on the stars, this buoy is located within a probable error of only about 400 yards—not so bad when one considers that it is two hundred miles beyond the sight of land.

The next step is the location of the remaining buoys of the chain relative to this end buoy. The station ship, anchored near the end buoy, has a hydrophone suspended under the keel and connected by wires with the radio set. The mobile survey vessel now steams over to the nearest buoy and, passing closely, drops a depth bomb composed of a quantity of T. N. T. The vibration caused by this explosion travels through the water to the hydrophone of the station ship, and its receipt is automatically and instantly flashed back to the survey vessel by radio. The elapsed time between the explosion at the buoy and the receipt at the hydrophone of the station ship is recorded within one hundredth of a second on a specially-constructed chronograph on the survey vessel. This procedure is followed at all the buoys and, with a knowledge of the velocity of sound in sea water, the distances between all buoys are determined and their positions thus located on the survey sheet.

It is positively uncanny to watch the time of the explosion recorded automatically on the chronograph, and again in ten to fifteen seconds to see, on the same instrument, the times of the receipt of the sound at the hydrophones of the station ships miles away.

The positions of all the survey buoys having thus been determined, two station ships can now be anchored at any two of the buoys and the mobile survey vessel steamed along on a system of sounding lines through fog or into the night, a depth bomb being dropped every ten minutes and thus positions obtained while underway in a manner similar to that used for locating the buoys. Some of the sounding lines extend to the thousand fathom curve, out beyond the edge of the continental shelf, yet the sound from these explosions travels through the water forty or fifty miles back to the station ships anchored on the bank, and their arrival is flashed back through the night to the survey vessel.

To-day such operations are taken as a matter of course in scientific progress. But two hundred years ago these scientists would have been burned at the stake!

METALS IN THE USE OF MAN

By Professor C. H. DESCH

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It is difficult for us, living in a world or railroads, of steel buildings and ships and of automobiles, to picture a time when man lived without knowing of the existence of metals. Yet for very many thousands of years the men of the Stone Age used only stone, wood and bone for their tools and weapons. The first metal that became known to man was gold. Unlike iron and copper, it does not have to be smelted from an ore, but may be found in the beds of rivers, conspicuous by its bright yellow color among the dull sands and gravels. Primitive men and women loved to decorate themselves, and this bright metal, soft enough to be hammered out into thin sheets, lent itself wonderfully to the making of gay ornaments. Later, as skill increased, it was worked into the most exquisite forms of flowers and fruits to make the head-dresses of queens, such as have been found in Mesopotamia and in Egypt and may be seen in our museums.

Copper and silver followed next. Like gold, they may be hammered out on a stone anvil with a stone hammer, but unlike it they tarnish in the air, so that the lumps found in nature are dull and not brilliant as is gold, making it more difficult to recognize them when they occur. Masses of copper up to thirty pounds or more in weight were hammered to shape by the mound builders of Ohio (to be seen in the museum at Columbus), and the men of even earlier times used the same means. It is only in a few regions, however, that copper is found as a metal, and usually it has to be smelted from its ores. Probably the discovery of smelting was accidental. Stones were used to build up the primitive fireplaces, and when it had happened that among those stones the bright green ore of copper had been used, a lump of metal would be found among the ashes and could be hammered into a tool. When some observant person noticed this fact the art of smelting was born.

In Asia, the art of working copper reached a high pitch, and copper tools, such as knives, were made by hammering the metal to a sharp edge, making it hard enough to use for cutting. It is sometimes thought that the ancients possessed some secret for hardening copper, but this is not so. The microscope tells us how their tools were forged, and we can obtain just the same hardness at the present day by the same means.

Then came a remarkable invention, that of bronze. Copper can not be made very hard, however much it is hammered, but when it is melted with tin, or when ores of copper and tin are smelted together, a very much harder alloy, bronze, is obtained. This alloy, too, can be cast into shape in stone or clay molds. How this discovery came to be made is still a mystery. The ores of tin are not brightly colored, like those of copper, and they are much less common. Somehow it was found that this alloy was better than copper, which it soon replaced. Even in the earliest graves of Ur, in Mesopotamia, which probably date from 3500 B. C., most beautiful objects of bronze are found together with those of copper. The Sumerian artists had wonderful skill in the working of metals as well as in that of wood, bone and ornamental stones.

Iron, the commonest of our metals today, was not used until long after bronze. Perhaps we may take about 1500 B. C. as the earliest date of its introduction. This may seem strange, but the lateness of its discovery has a simple cause. An open fire will melt copper or bronze easily, but even when burning fiercely in a strong wind it will not melt iron or steel. Smelting the ore in a fire yields a dirty, spongy lump, hardly recognizable as a metal. By careful heating and forging it can be made firm and compact, but this was only discovered late. Once the art had been mastered, it was found that iron made much stronger tools and weapons than copper or bronze, and its use soon spread. It may well be that the smelting of iron was first discovered in Central Europe, and that the art spread eastwards before the West learned anything of it. Certainly the Persians and Indians became masters of it, and the beautiful swords and armor which they made still excite our admiration.

It is true that we occasionally find objects of iron of much earlier date. For instance, the first graves at Ur have yielded a small axe, probably for ceremonial use, which is of iron, and a few other very early iron objects are known. But when we examine them by chemical analysis and by the microscope, we find that they were not smelted from ore, but were hammered out of pieces of meteorites, as some of the Eskimos make knives at the present day. As meteorites—lumps which appear as shooting stars and occasionally fall on to the earth from the sky—are not common, these iron objects were very precious, and we know from ancient writings that iron, before it came into common use, was prized above gold.

Although iron was used where hardness and cutting quality were important, bronze continued to be made, and some of the most beautiful of bronze objects belong to what we call the Iron Age. Silver, lead, and tin were also used, but were never so important as iron and bronze. Steel differs from iron in being harder, but it is made in the same way by heating longer in the charcoal fire. Steel is made much harder by quenching when very hot, and we find this process clearly described in writing as far back as Homer.

The Greeks and Romans brought to still greater perfection the arts of working metals practised by the Sumerians and the Egyptians, especially in the casting of large statues of bronze. The earlier bronze statues were made of hammered plates fitted on to a core of wood, but by casting much more magnificent work could be executed.

All down through the Middle Ages there was little change in the methods of working metals. In Europe and in Asia alike there were many craftsmen, and much of their finest work survives to this day. Water-power for blowing the furnaces took the place of natural draft or hand bellows, so that larger quantities could be melted, but for many centuries there was little change in the processes. In the 18th century came one of the great changes, the use of coal in place of charcoal in the smelting of iron, followed by the invention of many new processes. It was these inventions that made the steam engine possible, inaugurating what we call the industrial revolution.

It is impossible to speak to-day of progress in the 19th century. Such inventions as those of Bessemer changed the scale of production so that iron and steel, made 150 years ago in quantities measured by a few thousand tons, increased to their present production reckoned in scores of millions of tons. Our modern industrial civilization is based, not as sometimes imagined on gold, but on iron. Iron and its variety, steel, make possible our means of transport and the whole mechanical basis of our industry and life. The steel of today, however, is very different from that of the time of Homer. Means have been found to make it harder, tougher and stronger by special treatment, or by alloying it with other elements, some of them, such as vanadium and molybdenum, being rare metals which only a few years ago were merely chemical curiosities. Besides steel, new metals and alloys have entered industry—metals quite unknown to our forefathers. Chief among these is aluminum, a metal distributed widely in the earth, but needing such special means for its extraction that it remained unknown until our own time. Suitably alloyed and treated, it has properties rivaling those of steel.

The arts of peace and of war depend upon metals, and both have contributed to the progress of their production and working. The automobile and the airplane, with their high speeds and need for lightness, have perhaps done most to improve modern metals and alloys. Every year sees fresh progress in the field of metallurgy, and there is hardly any branch of the history of civilization more fascinating than that which tells how man has advanced from the Stone Age to the Metal Age of to-day, with its highly developed industries and complex organization. Would that we had been as successful in solving the problems of human relations as we have been in adapting the metallic riches of the world to human use!

ODDITIES OF THE OCEAN

By Lieutenant-Commander R. R. LUKENS

CHIEF, COAST PILOT SECTION, U. S. COAST AND GEODETIC SURVEY

WHEN you make a sea voyage on one of the many cruises which are so popular this winter, you may look across that apparently limitless expanse of ocean and decide for yourself, at least, that it certainly is one monotonous part of the world. If it be a bit rough and something you ate for lunch does not seem to set well on your stomach, you might even have a worse opinion of Father Neptune's domain.

To the oceanographer and hydrographic engineer, however, the sea and its mysteries are extremely interesting, and the floor of the ocean appeals to them as a great field for exploration. The bottom of the sea is the one place left that no one has ever seen—unless we except the biblical story of the children of Israel crossing the Red Sea—but still the hydrographic surveyor by taking accurate soundings and bringing up specimens of the bottom can produce a rather accurate map of it and give us considerable information concerning it.

This afternoon I would like to tell you of some queer things that officers of the Coast and Geodetic Survey have found in their 115 years of surveying our coastal waters.

First there is the remarkable submerged canyon of the Hudson, which lies about 50 miles at sea off the entrance to New York Harbor. If you take a chart of this section of the coast you can easily trace, by the deeper soundings, what geologists tell us was undoubtedly the course of the Hudson

River millions and millions of years ago before the eastern seaboard subsided and brought the shoreline to its present location at Sandy Hook and Coney Island. After following this ancient submerged valley for about 50 miles from Sandy Hook, we come upon a canyon which approaches the Grand Canyon of the Colorado in magnitude. Soundings show that the canyon at one place is more than 2,400 feet deep and about three miles wide from rim to rim. This grand gorge extends for about 20 miles until it spreads out fan-like and merges with the bottom of the sea. What grand scenery this canyon would make, but there seems to be no hope that any of us will ever get to see it. The canyon and old river valley serve one useful purpose, however, in that they form under-water landmarks for vessels equipped with echo sounding apparatus. In the case of a vessel bound from the Delaware Capes to Boston in foggy weather, the soundings tell the navigator when he is crossing this gorge and by referring to his chart, he can spot his position with entire confidence.

When Ponce de Leon was sailing along the Florida coast in search of the fountain of youth, he unknowingly sailed right by such a fountain two and one half miles offshore and nine miles south of the old city of St. Augustine. Here we have the unusual feature of an oceanic spring sending up millions of gallons of fresh mineral water from the sea bottom at a general depth of 55 feet. The bubbling up of this water produces a marked effect on the surface and it can be seen for a distance of one mile. A strong odor, quite similar to the sulphur springs of Florida, can be detected under favorable conditions when two miles away.

The water comes up with considerable force and creates such swirls that the officer who investigated it reported that it was very difficult to hold a boat over the spring. If the outlet of this spring were on land it is probable that it would resemble a geyser more than a spring. The spring emerges from a hole only about 25 feet in diameter and 125 feet deep, or 70 feet below the surrounding ocean bed.

Not to be outdone by Florida, California boasts of oil springs adjacent to her southern coasts. One of these is in the southern part of Santa Monica Bay near Redondo, and is located near the head of a deep submarine valley which makes in from sea. The oil comes up from a depth of 75 fathoms with sand and green mud bottom and covers a considerable area. Years ago when there was great rivalry between Redondo and San Pedro as to where a harbor should be built, Redondo used the oil spring as an argument in its favor, claiming that the oil produced by the spring would form a "slick" and in time of storm tend to keep the harbor entrance smooth. Apparently the Government engineers were not impressed, for the harbor was built at San Pedro, and is now known as Los Angeles Harbor. The oil spring was known to mariners many years before the oil prospector appeared on the scene and brought in the great oil fields that to-day exist in this vicinity.

Another oil spring occurs in the Santa Barbara Channel, a short distance west of the city of Santa Barbara. Here the smell of petroleum was so strong that the adjacent point was named "Coal Oil Point." Professor Davidson, who made the early surveys, stated that the smell of petroleum was almost overpowering and penetrated every part of a steamer which required about ten minutes to run through the coal-oil laden atmosphere.

You perhaps know that besides giving the depths of the water, the nautical chart shows the character of the bottom. Thus in looking over a chart will be seen abbreviations for mud, rock, sand, shells, etc., which indicate the kind of bottom in that vicinity. While the survey is being made the sounding lead is armed, as we call it, with tallow and after the sounding is made and the wire reeled in, the lead is examined to see what it has brought up.

At one place in Alaska, the chart shows gold dust as a bottom characteristic. This occurs about 18 miles southeast of Juneau in Stephens Passage and at a depth of some six hundred feet. Many prospectors have looked with greed at this indication of gold, but no one has ever yet devised a machine for dredging at such a great depth.

A curious feature of the waters of Alaska is the pinnacle rock. These lurking dangers often extend to within a few feet of the surface and have been the cause of many a shipwreck. The menace of these pinnacles was so great that the main ship channels of Southeastern Alaska have been swept by the wire drag and the pinnacles thus discovered are now charted.

One remarkable pinnacle was found which rose from a general depth of 600 feet to within 17 feet of the surface. This pinnacle is higher than the Washington monument, and, in fact, has been called the "Washington Monument Rock." It is fortunate that it was discovered by the wire drag before some unlucky ship struck it. In 1929 a large passenger vessel in western Alaska struck a charted pinnacle rock and went down in about seven and one half minutes. Only quick work in launching the life-boats averted a great loss of life.

In addition to her many high and spectacular volcanoes on land, Alaska has the very strange phenomenon of a submarine volcano. This is known as Bogoslof and is located in Bering Sea about 60 miles west of the village of Unalaska, and some 25 miles north of Umnak Island. It is out of the line of traffic and is only visited by an occasional cutter on patrol duty. Bogoslof rises up from depths of nearly 6,000 feet. It throws up islands and then blasts them away with terrific explosions. Nearly every year there are great differences in the appearance of the island. It is so seldom visited that no doubt many eruptions have gone unrecorded, but we know that great convulsions occurred in 1796, 1883, 1906 and 1910. The eruption of 1910 was witnessed by the officers of the *Tahoma*, who reported a column of steam and ashes many thousands of feet high. Of recent years great changes in the topography of Bogoslof have been reported, but no violent eruptions have been recorded.

Now and then we read stories of great changes in the ocean bed, islands disappear, rocks are shoved up and changes are reported in depths. Except for such localities as Bogoslof and where rivers discharge their load of silt and sand into the sea, the Coast and Geodetic Survey has seldom found any evidence of these changes.

One notable exception, however, occurred in the Sulu Sea in the Philippine Islands. In 1914 this area was surveyed by the Coast and Geodetic Survey, using standard methods of hydrography. A bank or shoal was found which was about two miles long and some half mile wide. This bank was carefully sounded over with closely spaced lines; depths of eight to ten fathoms with sand and coral bottom were found over the crest of the ridge.

Two years later, the surveying vessel under my command was instructed to do some supplementary sounding in this region, and in doing so, I ran a sounding line over this previously surveyed bank. We picked up the north end of the bank and our soundings agreed perfectly with the old work. Suddenly, when nearly half way over the bank, the Filipino leadsman sang out, "Twenty fathoms and no bottom." I thought the man had suddenly lost his mind, for I did not see how such a depth could possibly exist. I stopped the ship and took a cast with the sounding machine, and sure enough the depth was 32 fathoms; and this at the point where the previous survey showed ten fathoms! We went ahead and resurveyed the bank and found that while both ends were the same, the central part had sunk and that there now existed a 30-fathom channel between the two ends.

The two surveys were of equal accuracy and neither could be questioned, so that we could only assume that the central part of the bank had sunk or caved in to the extent of 20 fathoms, or 120 feet. No such vertical movement on land has ever been known even at the epicenter of the most violent earthquakes. What caused the subsidence, nobody knows. The records show that in the interim between surveys a severe earthquake had occurred in the vicinity and it may have been the cause, but there is no proof. This is the only case in which the Coast and Geodetic Survey has undisputed proof of a major change in the sea bottom.

While we are on the subject of the Philippines, you might be interested in knowing that the deepest sounding ever made in any ocean was had in 1927 by the German cruiser *Emden* at a point about 45 miles east of the Island of Mindanao in what has long been known as the "Mindanao Deep." The depth here was found to be 35,400 feet, or 6.7 statute miles. This spot is only 75 miles from a mountain 6,027 feet high; so we have here a difference of elevation of over 41,000 feet, which is 12,000 feet greater than the height of Mt. Everest, the highest mountain in the world.

The German vessel used echo sounding in determining the depth, but wire soundings have been made in depths of over 30,000 feet. Many people have the impression that, due to the enormous pressure, a weight will not sink to the great depths of the ocean. This is not the case. A cast-iron shot on the end of a piano wire, such as is used in deep sea sounding, will continue to go down until the bottom is reached. Due to the friction of the wire passing through the water, however, the wire pays out very slowly and it is difficult to tell the instant when the shot has reached bottom. Once the shot strikes bottom it is detached and the rod only is hauled back. A specimen of the bottom brought back in the hollow rod is proof that bottom was actually reached.

The Coast and Geodetic Survey is frequently called upon to search for what often proves to be phantom rocks. Lenard Rock in the North Pacific was such a case. Many years ago this rock was reported by sea otter hunters who claimed they had actually made fast their bidarkas to it. Later the captain of a trading schooner reported that he had lain becalmed in plain sight of the rock which was in the path of vessels bound from Seattle to Bering Sea.

If this rock really existed, it was a danger of the first magnitude, and every effort was made to verify the reports. Commercial vessels looked for it in clear weather, Government vessels were always on the alert for it and the Coast and Geodetic Survey spent several seasons making systematic surveys in the locality.

Lenard Rock was never found, and the evidence against its existence seemed so strong that it was taken off the charts and now the sea captains of a younger generation, unaware of the story of Lenard Rock, sail blithely by without thought of danger.

"GENES"—THE UNITS OF HEREDITY

By Dr. FRANK F. BUNKER
EDITOR, CARNEGIE INSTITUTION OF WASHINGTON

RECENTLY the interest of the scientific world was aroused by the announcement that Dr. John Belling, cytologist of Carnegie Institution of Washington, had actually seen the ultimate physical units of heredity in the cells of the lily, had counted and photographed them, and had observed somewhat of their behavior.

Until this announcement was made no one has thought that a *gene*, as the unit is called, had ever been seen. Like atoms, the existence of such entities has been inferred. A century ago, in attempting to explain the chemical behavior of substances, scientists found it necessary to assume the existence of atoms. All that has since been learned about the nature of matter seems well explained on the assumption that atoms exist.

So in biology, the results obtained from countless experiments in breeding plants, insects and higher animals can best be explained by assuming that genes actually do exist, that they are located, as separable particles, at definite and constant places in the *chromosomes* (carriers of heredity), and that these genes are responsible for those hereditary traits which distinguish one species from another and one individual from another.

HEREDITY VERSUS ENVIRONMENT

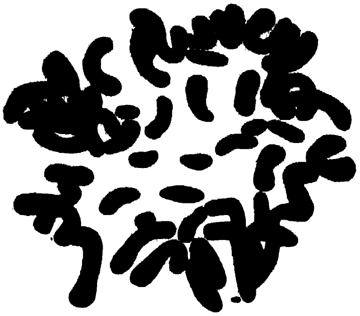
Ever since Carnegie Institution of Washington was established, twenty-eight years ago, its department of genetics has had investigators at work in study of the rôle which heredity and environment play in the life of plants, insects and higher animals, including man. As a result of their investigations and of those made by biologists working under the auspices of other agencies general agreement has been reached that every plant and animal is the product of two interacting influences.

One influence is the sum total of the internal factors that direct the development of the individual. This is heredity. The other influence is the sum of the environmental factors that determine the way in which the internal factors are able to express themselves in the development of the organism.

The actual appearance of an individual is the response of these internal factors to environment. Change in environment may modify the appearance of the individual to a greater or less degree; *i.e.*, its sum total of inherited factors respond differently to the surroundings.

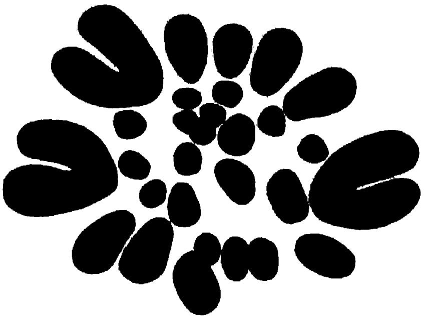
In speaking of these matters and of their implications Dr. C. B. Davenport, director of the Institution's Department of Genetics, says:

> The thoughtful person can never cease to admire the wonderful way in which the world of natural objects is reproduced generation after generation. We wonder, on the one hand, at the great diversity of species; on the other, at the marvelous precision with which each species is reproduced. We marvel, also, at the wonderful fitness of organisms to the world in which they develop and, in turn, reproduce.
>
> It is for the geneticist to give a scientific explanation of these phenomena, to bring under general laws the isolated facts of development, of diversity, of fitness.
>
> The first great advance in the scientific explanation of these phenomena was the tracing of the development of the individual by embryologists. The next was the discovery of the mechanism by which the internal factors that control development do their work. It is because the germ plasm—the chromosomes and their constituent genes—shows a continuity that the species reproduces itself. It is the failure of the former germ plasm to continue to reproduce itself in the same old way that is responsible for genetic variation or mutation. Yet



After Painter

MAN



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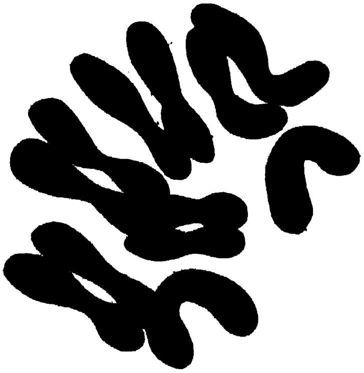
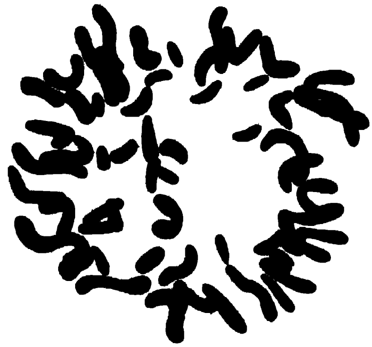


After Metz

HOUSE FLY



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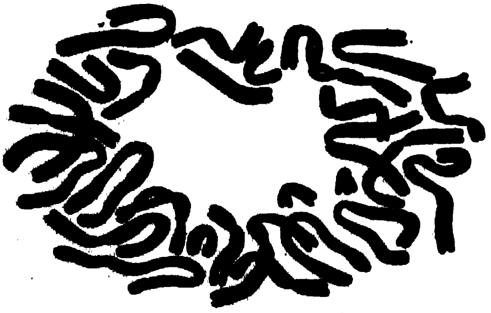
HORSE



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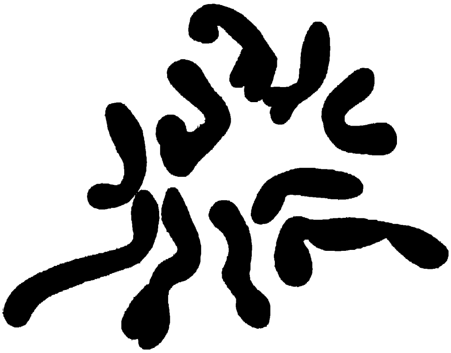
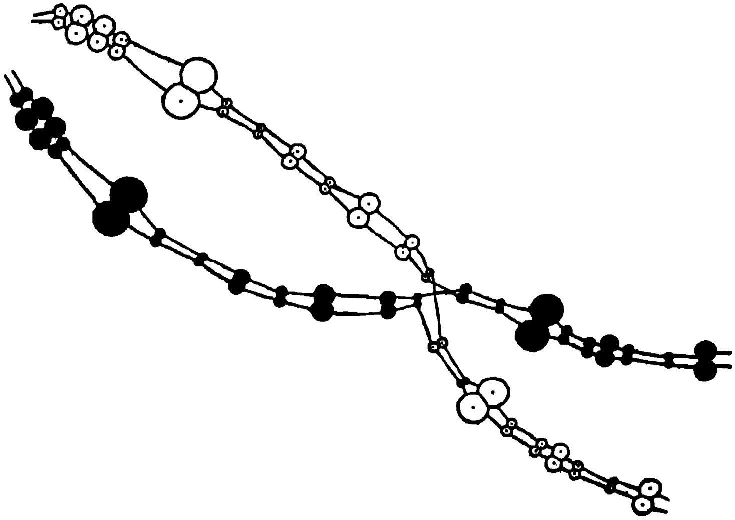


After Mann

PLANT—(*Crepis*)

DRAWINGS OF CHROMOSOMES OF VARIOUS ORGANISMS

As seen under the microscope, greatly enlarged. Chromosomes are structures in the cells of living things which, through fertilization and cell division, pass from parents to offspring. Each consists of a great number of genes strung together in a single row like beads on a string. The development of the individual, it is thought, is brought about through the interaction of these genes. Each species of plant and animal has a constant and typical number of chromosomes: man and the monkey have 48; the frog, 26; the pigeon, 16; the horse, 60; the fruit-fly, 8; the house-fly, 12; the lily, 24.



Drawing by John Belling

DIAGRAM SHOWING "CROSSING-OVER"

DIAGRAM, AFTER A CAMERA DRAWING, OF THE SEPARATION OF A SMALL PART OF THE DOUBLE CHROMOMERE STRINGS IN FRITILLARIA LANCEOLATA, SHOWING THAT THE TWO PARENTAL CHROMOMERE STRINGS (NOW BOTH DOUBLE) SEPARATE, AT FIRST IN MANY PLACES, LEAVING NODES BETWEEN. IN THIS CASE THEY HAVE "CROSSED-OVER" (EXCHANGED PARTS) AT THE NODE. DR. BELLING BELIEVES THAT JUNCTIONS OF THE CHROMOMERES AT A BEND, A CROSS, A TWIST, OR AN OVERLAP IN THE CHROMOMERE THREADS ACCOUNT FOR THE VARIOUS PHENOMENA CONNECTED WITH GENE BEHAVIOR OBSERVED BY GENETICISTS.

just that failure is regular; and the laws determining it are the subject of our investigation.

DR. BELLING'S DISCOVERY

For a number of years Dr. Belling has devoted all his time to research on the mechanism of inheritance believed to lie within the microscopic bodies called *chromosomes* which occur in the nucleus of every living cell. His investigations have taken him into study of the principles of optics as they apply to extremely high-power microscopes, into search for plants having chromosomes which could be studied to best advantage, and into development of an improved technique in preparing chromosomes for observation.

He found that plants of the lily family were especially suited to his purpose because in them the essential structures are more widely separated than in other plants. The Easter lily, the Madonna lily, the royal lily and the leopard or tiger lily of California were the members of this family which he most frequently examined; but it was in the last of these that he first observed the objects which he believes contain the genes.

Although, according to theory, genes are present in the tissue cells of plants and animals as well as in their germ cells, it is with the latter, more particularly the pollen mother-cells of the flower buds of the lily, that Dr. Belling works.

He takes the anthers (pollen-bearing flower parts) when they have reached the proper stage of development, cuts them open and presses the mother-cells of the pollen out on to a clean glass slide which he instantly immerses in a fixing solution consisting of a combination of powerful chemical agents. It is important, he finds, that the cells be killed instantaneously; for if they are permitted to die slowly the structures which he wants to observe fuse and lose their distinctive appearance.

Having thus completed the preliminary preparation, he subjects the slides to treatment with various staining solutions which the cell structures absorb in differing degree, thereby making them more easily distinguishable under the microscope.

So skilful in manipulating these diminutive pollen mother-cells has Dr. Belling become, and so successful has he been in finding dyes which give maximum visibility, that even though the cells themselves are less than one four-hundredth of an inch in diameter, a size which is below the limit of unaided human vision, yet in these tiny containers he has seen and counted at least 2,200 different bodies which he thinks are the ultimate units of the inheritance mechanism.

In the living plant, Dr. Belling states, a coat of stainable matter forms around the genes so thick and viscid that it can be pulled out into long strings. A gene with its coat of stainable matter is called a *chromomere.* Each of the strings of *chromomeres,* of which there are 24 in the tissue cells of the lily, constitutes a *chromosome.*

Dr. Belling has counted the *chromomeres* in the lily and showed that each contains a single core which is barely visible when conditions are most propitious; that these are plentiful enough to satisfy the theoretical requirements of gene numbers; and that the various phenomena connected with gene behavior, designated by geneticists as "crossing-over," "inversion," "translocation," "deletion," and "deficiency," can be accounted for by junctions of the *chromomeres* at a bend, a cross, a twist or an overlap in the chromatin threads.

IMPORTANCE OF THE GENE

In commenting upon the function of these structures, Dr. Belling says:

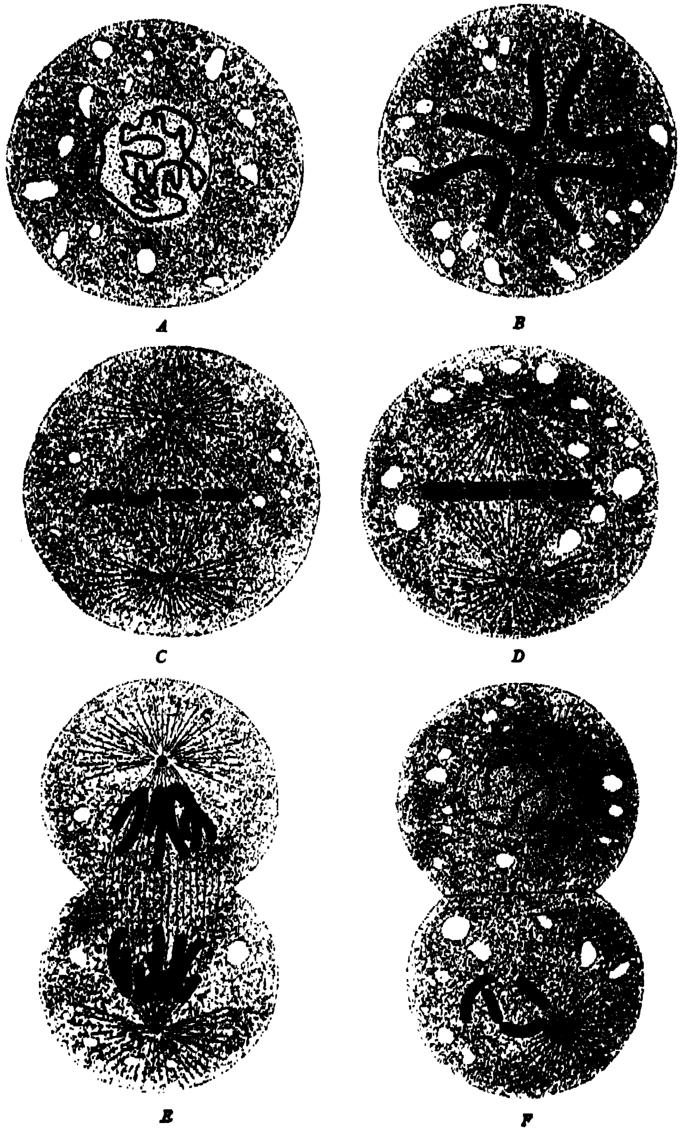
> A minute cell sphere with its 2,200 gene pairs suggests the celestial sphere visible to the unaided eye and containing fewer than 3,000 stars which can be seen at one time. These stars were supposed by some to exert a mystic influence on human beings. In the spherical cells of the organism, however, the genes actually do exert specific influences on the life of the organism in question, whether of the lily or of man. In fact these influences are so great that if the effects of all the thousands of genes in a given organism were added together nearly the whole of its inheritance would be accounted for.
>
> These strings of chromomeres are of more consequence, therefore, than the threads of life which, according to the old fable, the Fates were supposed to spin. Indeed, in many of the old sayings relating to the influence of the stars, if the term "gene" or "chromomere" be substituted for "star" the saying would hold to-day. Could we but identify every one of the chromomeres in a man (probably there are many more than in a lily), a reliable horoscope for him could be drawn up.

The relevancy of Dr. Belling's remarks concerning the influence of genes or chromomeres in heredity will become apparent when it is realized that the method by which the cells of plants and animals divide is such as to make certain that genes from both the parents are transmitted to the offspring. A quick review of the description which cytologists give of the basic features of the method will make this clear.

THE FORMING OF CHROMOSOMES

Nearly all living things begin with the fusing of two sex-cells, one from the male and the other from the female. This is fertilization, whereupon development begins. The single fertilized cell thus formed divides into two cells, these into four, the four into eight and so on until, in time, there are millions of cells organized, in the case of plants, into roots, stalks, leaves, flowers; and, in the case of animals, into bones, muscles, blood, heart, brain and all the other tissues of the animal body.

In one respect the living cells, whether of plant or of animal, are all alike—they are filled with water and, moving



After A. Franklin Shull in "Heredity," McGraw-Hill Book Company

STAGES OF CHROMOSOME DIVISION

SHOWING THE STAGES THROUGH WHICH THE CHROMOSOMES OF ASCARIS, A PARASITIC THREAD WORM, PASS WHEN CELL DIVISION TAKES PLACE. DRAWINGS OF ACTUAL SPECIMENS CUT IN THIN SECTIONS. *A*, EARLY STAGE, CHROMATIN THREAD SLIGHTLY CONDENSED; *B*, CHROMATIN THREAD HAS FORMED INTO CHROMOSOMES WHICH ARE ARRANGED ACROSS THE MIDDLE OF THE SPINDLE; *C*, SAME AS PRECEDING, VIEWED FROM THE SIDE OF THE SPINDLE, WITH CHROMOSOMES NOT COMPLETELY IN THE SECTION; *D*, CHROMOSOMES SPLIT LENGTHWISE; *E*, CHROMOSOME HALVES MOVING APART, CELL BODY BEGINNING TO DIVIDE; *F*, DIVISION OF CELL BODY COMPLETE, CHROMOSOMES IN CELL AT TOP BEING RECONSTRUCTED INTO A NUCLEUS.

through it, is a substance called *protoplasm* which holds suspended in it, usually in a central position, a spherical body of somewhat denser material called the *nucleus*. The nucleus is of great consequence, for it is known that it exercises a controlling influence on the physiological activity of the cell. It is also of particular importance in heredity.

When the cell is quiescent the nucleus apparently consists of a tangle of fibrous material. In preparation for cell division these threads appear to shorten and thicken, forming segments, twenty-four in the lily, forty-eight in man. These rod-like bodies in the nucleus, seen at this stage, are the chromosomes.

THE SPLITTING OF THE CHROMOSOMES

The chromosomes quickly take an orderly position at the middle of the cell, whereupon fibers develop which connect each chromosome with opposite "poles" of the cell.

When this stage is reached each chromosome splits along its length. Thus two sets of chromosomes are formed, each set being a counterpart of the original set. The two sets then pass to opposite poles, drawn there, some think, by the contraction of the fibers, whereupon the cell divides. Two cells are thereby formed, each containing a set of chromosomes which is exactly like the set contained in the sister cell and both exactly like the parent set from which they sprang.

In these new cells each group of chromosomes takes a central position and reforms a spherical nucleus from which, after a resting period, chromosomes again emerge when these daughter cells, in their turn, are ready to divide. Through repetition of this process all the tissues of the individual plant or animal are built up of cells containing chromosomes which are all directly "descended" from those originally present in the fertilized egg.

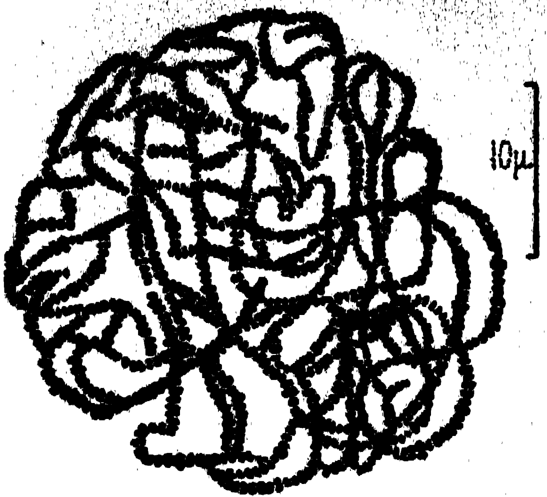
We have said that the process just described is such that a guarantee is had that the cells of the individual plant or animal shall contain all the chromosomes characteristic of the species to which it belongs. This is true of all the cells of a given individual excepting only that group in each instance which is concerned with reproduction. By a striking modification of the process of cell division, the chromosome number in the germinal cells of both sexes is reduced to one half the characteristic number.

REDUCTION DIVISION IN GERM CELLS

The reason for this reduction in chromosome number is obvious. If there were no reduction, when the male and female cells unite the fertilized cell would contain double the characteristic number. In each subsequent generation the number would again double and so on indefinitely; thus a wholly absurd situation would soon arise.

As these germinal cells develop, the chromosomes in them come together in pairs while still very thin instead of splitting longitudinally and forming duplicate sets as they do in the ordinary tissue cells. The members of each pair, instead of the halves of each chromosome, separate to opposite poles, whereupon the cell divides into two cells. In this manner the number of the chromosomes is reduced one half, the full number being restored when fertilization takes place.

However, before the cells formed by this process of reduction mature and become capable of functioning in reproduction they undergo one further division which, it should be noted, does not change their chromosome number. That is to say, from any cell that undergoes this reduction division four cells are finally derived. In the male, whether of plants or of animals, all four become sperm cells capable of fertilizing the female. In the case of the female among animals, only one of the four develops



Drawing by John Belling

CAMERA DRAWING OF A CHROMOMERE STRING.

into an egg, the other three remaining functionless and clinging to the side of the egg in the form of small rudimentary cells known as "polar bodies."

Exceptions Noted

Although the foregoing steps in chromosome behavior are sufficiently general among plants and animals to justify the conclusion that they are typical, nevertheless, as investigation continues, significant modifications in the processes are found to exist. These relate particularly to the behavior of the so-called sex-determining chromosomes. Moreover, the work of Dr. C. W. Metz, of the Department of Genetics, on the fungus gnat, *Sciara*, shows that with this genus at least there are peculiarities in chromosome action which put it in a class apart and which open up problems the solution of which may throw much light on uncertain and little understood aspects of the inheritance mechanism.

For the general reader, however, the important things to remember about the basic features are these: that there is a method of cell division common to practically all plants and animals which insures that all the cells of the individual except the reproductive cells shall carry the full number of chromosomes characteristic of the species; that the reproductive cells in each case shall contain one half of the characteristic number (except as modified in respect to the sex-producing chromosome); and that when the fusing of the male and the female cells takes place in fertilization the characteristic number is reestablished.

The most striking feature of cell division, then, is the longitudinal bisecting of the gene strings (chromosomes) and the provision whereby every daughter cell is granted its full complement of these priceless genes, presence of which, according to all available knowledge, is essential to continuity of life, of organization and of species.

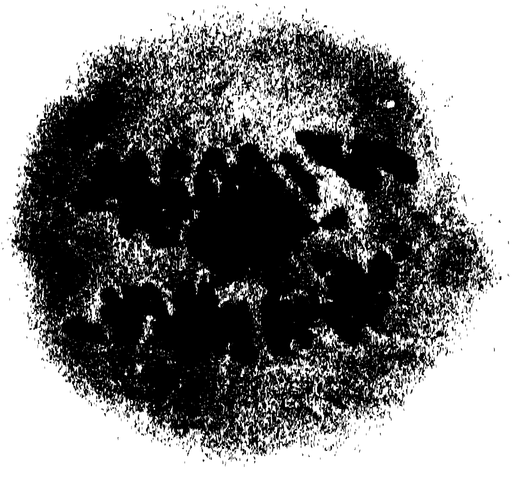
Study of the Fruit-fly

The work on the fruit-fly (*Drosophila*), begun by Professor T. H. Morgan, of Columbia University, and continued by him and his students, supplemented by investigations in other institutions, is chiefly responsible for establishing this gene theory of heredity. By breeding, literally, millions of pedigreed flies and observing the results, Morgan and his students have been able to identify the genes responsible for many of the characters which appeared in the adult flies and to prepare diagrams to show the locations of the controlling genes in their respective chromosomes.

At one time it was thought that for every character appearing in the adult there is a gene to correspond: that, for example, there is a particular gene which controls wing shape; one which determines eye color; another which is responsible for head shape; and so on for all the other characters.

The work on the fruit-fly, and that done in other investigations, however, proved this view to be untenable. It showed, for instance, that red eye color in this fly is the end product of the co-operative action of a troop of genes, of at least fifty in this case; that the wing of the fly is a complex requiring the interaction of hundreds of genes; and that all the other characters are responses in each instance to the influence of many genes.

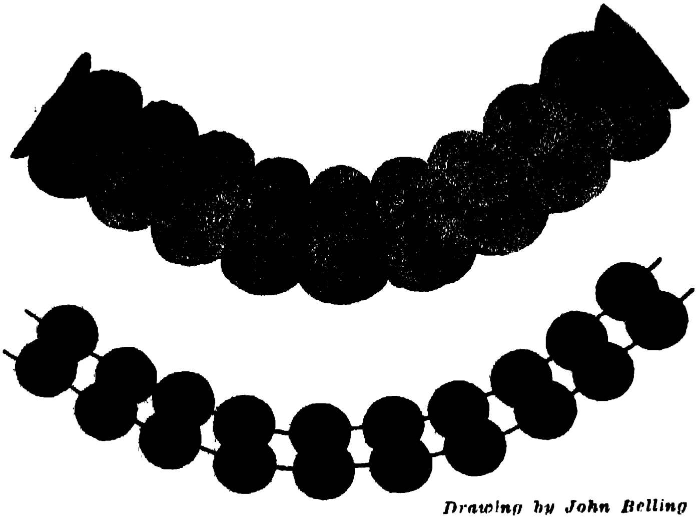
In turn, each gene may affect many characters. Alter a single gene in a co-operative group and the character which is the result of the interaction of the members of that group will be altered. Thus a change in a single gene in the fruit-fly may rob the eye of all color, giving a white eye, or it may change the typical shade of red to another slightly different. And what is true of the fruit-fly in these matters applies equally well to all other organisms, including man, insofar as they have been studied.



Photograph by John Belling

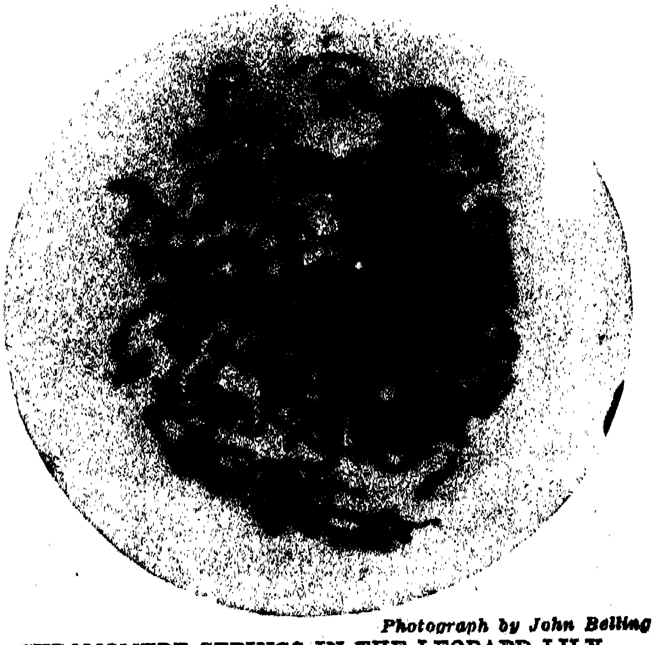
A PHOTOGRAPH SHOWING THE COMPLETE SEPARATION OF THE SPLIT CHROMOSOMES

OF THE TWELVE PAIRS FROM THEIR MATES IN THE LILY. ANOTHER DIVISION FOLLOWS, SEPARATING SIMILARLY THE SPLIT HALVES. THEN GROUPS OF TWELVE CHROMOSOMES ARE READY TO PASS AS PARENT GENE STRINGS TO NEW LILY SEEDS. BY THE INTERCHANGES WHICH HAVE TAKEN PLACE, NOT ONLY HAVE THE TWELVE CHROMOMERE STRINGS OF ONE PARENT BEEN SHUFFLED WITH THE TWELVE STRINGS OF THE OTHER PARENT BUT A SMALL AMOUNT OF SIMILAR SHUFFLING OF THE CHROMOMERES HAS OCCURRED.



Drawing by John Belling

UPPER—A DOUBLE ROW OF CHROMOMERES IN THE POLLEN MOTHER-CELLS OF ALLIUM (THE ONION FAMILY) AS SEEN UNDER THE MICROSCOPE, GREATLY ENLARGED. THE CHROMOMERES HAVE BEEN SQUEEZED FLAT SHOWING THAT THERE IS AN EXTREMELY MINUTE GENE IN EACH. LOWER—A DRAWING REPRESENTING THE ABOVE DOUBLE STRING OF DEEPLY STAINED CHROMOMERES BEFORE DESTAINING AND SQUEEZING FLAT. THE CHROMOMERES IN MANY PLANTS AND ANIMALS ARE SO SMALL THAT ESPECIALLY ACCURATE MICROSCOPY IS REQUIRED TO SEE THEM AT ALL.



Photograph by John Belling

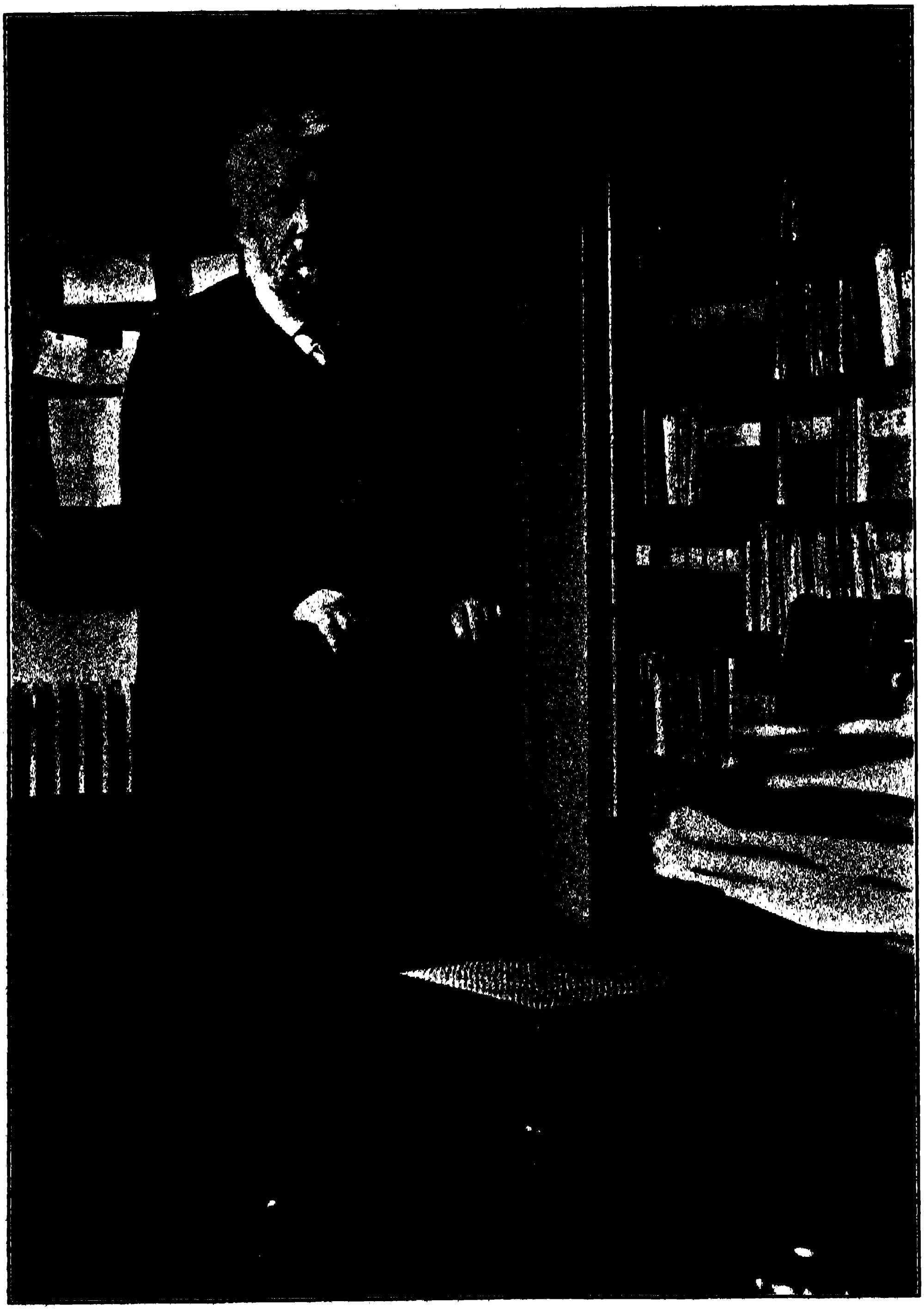
CHROMOMERE STRINGS IN THE LEOPARD LILY.

EXISTENCE OF GENE CONFIRMED

In the light of these considerations genes have been compared to discrete packets of different chemical substances (super-molecules, perhaps) bound together loosely into chains. Each chain constitutes a separate chromosome made up of an enormous number of these packets of heredity, 2,200 in all the chromosomes together, Belling says of the lily. Through the various processes taking place in the cell these packets are paired, distributed and reassembled into new combinations, obeying in so doing certain definite laws of heredity.

It would seem, therefore, that explanation of the various ways in which the individuals of a given species develop, whether plant, insect or man, of the peculiarities and diversities that give them individuality, and of the extraordinary resemblances and differences that exist between parent and offspring, requires the assumption that there actually exists a constituent physical entity in the chromosome which is passed along from generation to generation and that this is capable of bringing about the development in the new generation of the same character which its progenitors had developed in the parent generation.

Dr. Belling's announcement that he has seen this ultimate entity; that he has photographed it; and that he has watched its behavior in the several stages of cell division is another of the many striking instances in scientific investigation of how conclusions reached theoretically may later be confirmed by direct observation.



WILHELM OSTWALD

A PHOTOGRAPH WHICH FORMERLY HUNG IN THE LABORATORY OF JACQUES LOEB AT THE ROCKEFELLER INSTITUTE. THE ORIGINAL WAS LOANED TO THE SCIENTIFIC MONTHLY BY DR. W. J. V. OSTERHOUT

THE PROGRESS OF SCIENCE

WILHELM OSTWALD

Wilhelm Ostwald, born in September, 1853, at Riga, Latvia, died, in his seventy-eighth year, on April 4 of this year. In him a very brilliant star in the world of science has been extinguished; one might say a star as brilliant as a meteor, if this comparison did not imply a lack of endurance, for this would be the least appropriate attribute to assign him. His characteristics, rather, were steadiness of character, untiring energy in achievement and a strong permanent influence upon the world, not only of science, but also of philosophy. If one asks what was the greatest strength of Ostwald, one might say it was his power of organization, and even this statement, without further comment, may convey a misunderstanding. He not only organized material produced by others and otherwise scattered, but he himself contributed to a considerable extent to the experimental and theoretical data which he so successfully endeavored to organize. His special field of experimental work was in physicochemistry, and this work alone would earn for him a place among the great chemists of his period. It was this work for which, in 1905, he received the Nobel Prize in chemistry.

His first experimental work, which concerned the affinity constants of acids, made it possible to measure the strength of acidity in a quantitative way. His first remarkable achievement in organization was his text-book of general chemistry which was at that time an altogether novel attempt to present chemistry as a science, logically coherent in itself, like physics.

Ostwald studied chemistry and physics at the University at Dorpat, the intellectual center of Livonia, and in general of those Baltic countries which, though outside the borders of the German Reich, were then intellectually dominated by Germans. He became assistant in physics there in 1875, and was appointed professor at Riga in 1881. Here he performed his investigations on the affinity constants of acids, a work early recognized, on the merits of which he received a call to the University of Leipzig in the year 1887. He remained in Leipzig even after resigning from his professorship, living in a suburban home to which he gave the name "Energie," a word very characteristic of him, both with respect to its physical and ordinary meaning. Energy, in the physical meaning of the word, was to him the essential elementary principle, much more real than matter. The energetic point of view in physics and chemistry was to him much more fundamental than the atomistic point of view, so much so that he used the atomistic theory as a mere working hypothesis and was not quite convinced of the real existence of molecules and atoms. The latter view-point, of course, belongs to a period of science which had acquired a rather different aspect due to facts observed and theories established after Ostwald's main period of activity had passed.

The institute created by him at Leipzig became one of the prominent centers of attraction among the German universities, comparable to that of Giessen in Liebig's time. Physicochemistry had become a recognized branch of chemistry mainly due to the centralizing influence of his laboratory at Leipzig. In this period the fundamental laws of what later was called physicochemistry were unfolded by van't Hoff, and a little later by Arrhenius, and by Nernst, who began his career as one of the first assistants of Ostwald. Ostwald's laboratory was the center of this new branch of science, from where it spread throughout the world. Young chemists from all lands were attracted by his personal influence and through his text-book on general chemistry. He taught these young men that the task of the chemist was not only the preparation and analysis of new compounds, but also the establishment of the physical laws generally underlying chemical reactions. It took quite a time for the older generation of chemists to appreciate the fact that something could be achieved in chemistry, even though no new compound had been prepared. A whole generation of physicochemists has sprung up through the inspiring influence of Ostwald's laboratory. There was in fact in the decades to follow practically no physicochemist in Germany who was not a disciple of Ostwald, and a great many foreign physicochemists originated from or at least sought contact with his laboratory.

His activity at the University of Leipzig lasted fifteen years. The yield in publications of this period is vast, and is deposited in the *Zeitschrift für physikalische Chemie,* founded by Ostwald himself, together with van't Hoff, as the organ of the new branch of science. The first volumes, and I do not mean by this only the first five or ten, may be looked upon to-day as the bible of physicochemistry. Not only did he and his pupils accumulate in this journal a huge amount of material covering experimental work, but scientists the world over used it for their publications. Ostwald availed himself of his journal also for publishing numerous book reviews. The number of books he read and reviewed at this time, always in his invigorating and critical fashion, is almost inconceivable.

It is obvious that a man of such influence was something more than a gifted experimenter in the laboratory. Ostwald was, in addition, a great practical psychologist and knew something of men. He not only discovered facts but also men. In this respect two discoveries should be mentioned which belong among his greatest: The discovery of the American, Willard Gibbs, and of the Swede, Svante Arrhenius. One can not be certain that the work of Willard Gibbs might not have remained buried in the Proceedings of the Academy of Connecticut to the present day if Ostwald had not drawn it into the limelight. He recognized not only the greatness of this American but also the reason why his great work remained practically unknown. Gibbs was in one respect almost the opposite of Ostwald. He lived a retired life, did not aim at a personal influence on men, and deposited his discoveries in such a generalized and abstract way that the chemists of his day could not guess at their real significance. It was Ostwald who gave Gibbs' ideas comprehensible form. Arrhenius' work also might have remained unappreciated or belittled for a long time, had not Ostwald from the very beginning become the enthusiastic partisan of Arrhenius' theory of electrolytic dissociation. It took a long time to convince the chemists of the truth and bearing of this revolutionary theory. The reason why just Ostwald should recognize this so early was not only the ease with which he grasped new ideas in general but the fact that Arrhenius' hypothesis explained in a most simple manner the laws which Ostwald had discovered for the general properties, especially the electric conductivity, of electrolytes. Through Arrhenius' hypothesis it became possible to recognize in Ostwald's so-called law of dilution for electrolytes a particular case of the mass action law established by Guldberg and Waage, and by van't Hoff, and to apply it to electrolytes. Hereby the applicability of one great fundamental law in chemistry, the law of mass action, was found to cover a very much greater field than its discoverers had anticipated. It meant the establishment of a very comprehensive law covering the whole of chemistry which aroused Ostwald's interest in Arrhenius' hypothesis.

His active, keen interest in the work and the personalities of his fellow-scientists, as manifested in his promotion of the work of Gibbs and Arrhenius, was one of Ostwald's outstanding characteristics. He considered everything and anything from the standpoint of its personal and historical development and devoted an unusually large amount of time to historical presentation of the personal lives of the discoverers of the universal laws. He carried this so far that he became what we may call a professional biographer of scientists and even of other great men: so much was he convinced of the inseparability of science and the personal element linking the discoveries and the discoverers. His systematic way of studying even these more psychological things found expression in his book, "Grosse Männer," in which he analyzes the characteristic features of a genius, classifying great men in what he called the classical and romantic types. This trend of his mind caused him to publish the series "Klassiker der exakten Wissenschaften," a collection of reprints of papers old and new, which he considered milestones in science. This collection is missing in scarcely any scientific library to-day.

A common thought permeates his studies on the development of a genius. It is a discontent with the educational system of the "humanistic Gymnasium" in Germany as conducted at that time, in which the study of Latin and Greek exclusively was utilized for the training of the mind, and natural science was scorned. It is not easy to imagine at the present time and in this country how much courage was requisite for such a combat against the well-established and standardized educational system. He himself was certainly not a good student in his Gymnasium days. This was not because he was not gifted but because he was too much distracted from his school work by diverse interests. His mind was occupied with practical engineering problems, experiments in the field of the natural sciences and collecting in a more biological field. When he graduated from the Gymnasium and entered the university he was greatly distracted from the regular curriculum by a thorough enjoyment of the hilarious student life characteristic of German universities. When, after paternal admonition, he took to earnest study, he surprised every one by reaching his graduation in an unbelievably short time. All his life he fought for a renovation of the educational system and in spite of great reluctance a change has taken place in the direction suggested by him.

He retired at a comparatively early age from his professorship, in conformity with a principle which he always emphasized in his biographical studies, namely, that all great achievements of a genius are merely elaborations of ideas acquired in youth and that no new fundamental idea is originated in later life. He believed that physicochemistry might be more fruitful of progress if another generation were allowed to unfold it. On the other hand, he had gathered from his youth such a rich collection of ideas outside physicochemistry that he decided to elaborate these rather than to follow the course of physicochemistry which gradually began to turn in new directions.

Among the subjects which he pursued after his retirement, two may be mentioned, one of a philosophical or rather theological nature, the other lying on the border-line of physics and art. The first of these two is the cause of monism. Jointly with Ernst Haeckel, the zoologist and propagator of Darwin's ideas, he worked for the cause of monism. He published the pamphlet, "Christendom as Forerunner of Monism" and the series of "Monistische Sonntags-Predigten." Not only in his chemistry and physics but also in his theories on psychological behavior, even to the point of religious ideas, the concept of energy plays a central part.

The other subject which occupied his mind in later life was a theory of colors. Painting had been a favorite and successful occupation of his. Even to this he tried to apply a scientific method for the demonstration of the problem of color harmony. His occupation in this field led him to develop a color system which aims at describing any shade of color by attributing to it three properties, each measurable in a quantitative way. Each color is supposed to be composed of a certain quantity of black, white and color proper. Although the physical basis of the theory has not been unanimously accepted, yet the practical result of the establishment of a color system by which it is possible to reproduce every shade of color by three attributes, has been recognized as a practical solution of the problem.

Another favorite subject of Ostwald's was Esperanto, the artificial international language, and he was much interested in encouraging its more widespread use. He also realized the importance of, and worked toward the standardization of publications with respect to size, printing type, binding, international standard coin and so forth, for the sake of simplicity, systematic order and clearness.

If one were to choose which of Ostwald's scientific achievements may be considered most outstanding, the work selected would vary according to the sphere of interest of the chooser. The author of this review would emphasize the work on the definition and measurement of strength of acidity; his work on catalysis, especially the catalytic oxidation of ammonia to nitric acid and the elaboration of the theory of catalysis beyond the point to which it was brought by its originator, Berzelius; and the first development of those ideas on selective permeability of membranes for various ions which is still the subject of many experimental studies and which may ultimately lead to an understanding of the electric phenomena in living organisms.

The significance of a man like Ostwald, however, is by no means exhausted by an enumeration of his scientific achievements. He was a great personality and a fighter in the cause of logic, reason, justice, honesty, peace and humanity.

Leonor Michaelis

SCIENCE IN JAPAN

ABOVE IS SHOWN DR. TAKHIRA, IN CHARGE OF THE KOISHIKAWA NUTRITION LABORATORY IN TOKIO, WHO IS CARRYING ON RESEARCHES ON METABOLISM. BELOW, A JAPANESE STUDENT IS HAVING A PSYCHOLOGICAL TEST AT THE KOISHIKAWA OFFICE IN TOKIO

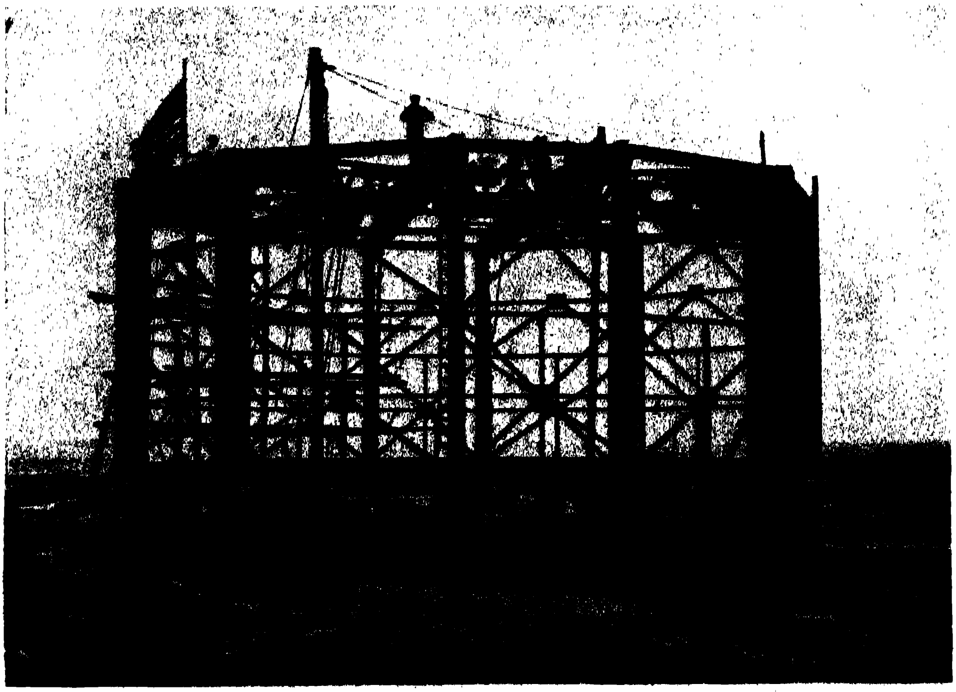
THE BOYDEN STATION OF HARVARD COLLEGE OBSERVATORY IN SOUTH AFRICA

FORTY-ONE years ago, in 1891, a generous fund left by Uriah Atherton Boyden, a mechanical engineer of Boston, enabled Harvard College Observatory to fill a need of fundamental importance and to establish, two miles north of the capital of Southern Peru—Arequipa—on the western slopes of the Andes and at an elevation of 8,050 feet, its southern branch, known as the "Boyden Station."

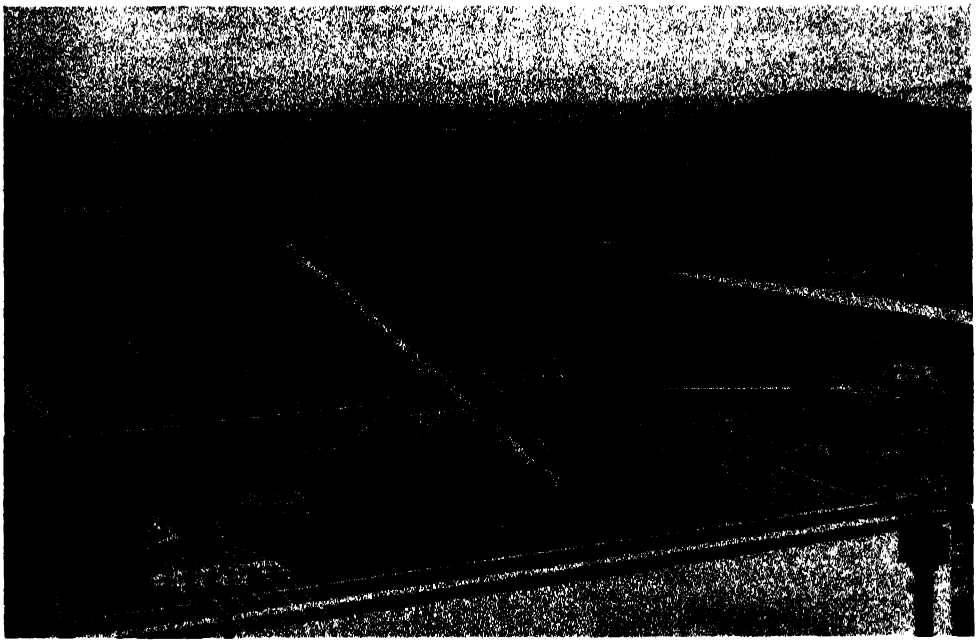
From the purely astronomical standpoint, Arequipa was not an ideal place for an astronomical observatory, due to a practically continuous spell of cloudy weather lasting from November to March or April. However, the choice of a suitable site in southern latitudes was at that time very limited indeed. Communication between the United States and the continents of the southern hemisphere was hardly developed, and living and sanitary conditions left much to be desired, disregarding even the dangers from frequent revolts and political uprisings which seem to be endemic in many of the southern republics.

Arequipa was always considered a temporary site and, as early as 1908, the late Professor Bailey came to South Africa to study the prevailing atmospheric conditions and to look for a permanent site.

Bailey's investigations brought to light the superior qualities of the South African high plateau ("high veld") but the financial status of Harvard Observatory in 1908 and subsequent years did not permit of the heavy expense involved in the transfer of the Boyden



THE TURRET AND THE UNDERGROUND BUILDING
FOR THE 60-INCH REFLECTING TELESCOPE AT HARVARD KOPJÉ. (PHOTOGRAPHED IN NOVEMBER, 1931)



THE BRUCE 24-INCH REFRACTOR

Station from South America to South Africa. The great war and the death of the director of Harvard Observatory, Professor E. C. Pickering, with the ensuing unsettled period of practically three years during which Professor Bailey was acting director, postponed matters indefinitely.

The appointment in 1921 of Dr. Harlow Shapley as director of Harvard Observatory marked the final phase in settling the question of the Boyden Station.

As it was thought that suitable sites could be found in South America, and the heavy expenses of moving from one continent to another could be obviated, the writer, at Professor Shapley's request, undertook three expeditions between the years 1923 and 1926 in the high plateaus of Northern Chile (elevation 9,500 feet) and the pampas of Southern Peru, testing sites and studying atmospheric conditions. At the same time, data concerning the prevailing sky conditions in several parts of Australia were kindly submitted by the authorities there for perusal.

The results thus obtained showed that the balance of arguments was greatly in favor of the South African high veld, which was therefore selected as the permanent home for the Boyden Station. Generous gifts from the International Education Board and from Harvard University enabled Dr. Shapley to take his final steps. Late in 1926 the Boyden Station at Arequipa was dismantled and in 1927 the instruments, library, etc., were shipped to South Africa *via* New York. The writer arrived in South Africa in July, 1927, and work for finding the best site and establishing the Observatory started at once.

The interest shown by the South African people in the establishing of the Boyden Station is worthy of high praise, and the first months of my stay in this country were filled with continuous delightful surprises.

After a careful examination of localities and conditions, Mazelspoort was finally selected as the site for the station. The site—a low hill rising about 200 feet above the surrounding veld, which is itself 4,500 feet above sea-level—is situated ENE and at a distance of 15 miles from the town of Bloemfontein, the capital of the Orange Free State, and is to-day officially known as "Harvard Kopje" (kopje being the South African word for hill). The grounds, about 14 acres, were generously presented to the observatory by the municipality of Bloemfontein, which also constructed the road leading to the top of the hill, installed water and power mains together with fire protection, and gave the services of the city's engineer and staff, all free of charge.

To-day, there are five photographic telescopes in continuous operation, their apertures ranging from 3 inches up to 24 inches. In addition there is a transit instrument, mainly for the determination of time.

In July, 1931, work was started for the erection of the building (semi-pit type) and of the turret to house a reflecting telescope of 60-inch aperture, and it is hoped that this instrument will be in operation about the middle of the current year.

The work carried on at the Boyden Station, which, with the equipment at its command and the unlimited field of the southern sky for exploration, constitutes one of the main arteries of Harvard Observatory, is purely photographic. The program, outlined by Director Shapley, bears on the structure of our Galaxy, the extragalactic objects, the Super-Galaxies and the Metagalaxy, and will necessitate many years of continuous but pleasant work both at the telescope and in the office.

It is very gratifying to state that the results reached so far are very promising indeed and highly encouraging.

J. S. Paraskevopoulos

Harvard Kopje,
South Africa,
February 6, 1932

THE U. S. FOREST PRODUCTS LABORATORY

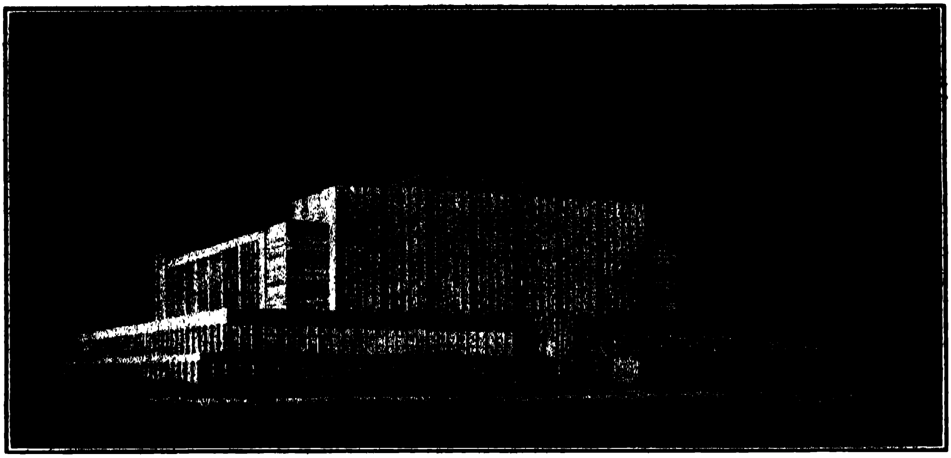
Work is well advanced on a new building for the U. S. Forest Products Laboratory, at Madison, Wisconsin, which has been under construction since August.

The Forest Products Laboratory is devoted to the better understanding of the properties of forest materials and to broadening the fields of use for forest products. In its six stories, with total floor space of 175,000 square feet, the new building will contain modern facilities for investigating and testing wood and other forest products with respect both to their fundamental properties and their many uses.

A large group of dry kilns equipped for close control of temperature, humidity and air circulation will help to solve the problems of seasoning many species and types of wood. A cold storage chamber will be provided in which green logs and timber can be kept in unchanged condition for experimental work at any time.

Since every step of wood manufacture and construction and the satisfactory performance of wood in service are influenced by moisture conditions, a number of humidity rooms will be provided in which wood can be brought to the exact moisture content desired for study under conditions simulating any season of the year or any climate of the temperate zone.

Machines for testing timbers and framework up to a breaking load of 1,000,000 pounds will be available in a testing gallery accommodating pieces and panels as large as 30 feet high and



THE U. S. FOREST PRODUCTS LABORATORY

100 feet long. Tests of boxes and shipping crates can be carried on at any degree of dryness or dampness that would be met in service by storing and testing the containers in a special moisture-control room served by movable machinery.

The pulp and paper research laboratory, occupying six floors at one end of the building, will include grinder equipment, a digester tower 40 feet square, beating and refining apparatus and an experimental paper machine, with all moving parts under precision control. With this equipment the study of various American woods as pulp and paper raw material will be continued, along lines that have already broadened the pulpwood market and pointed the way to improved chemical pulping.

Among unusual features of the building will be an ultra-violet ray chamber, where wood can be sterilized for mycological studies and where paints and other materials can be exposed for test, an x-ray room providing for the examination of the minute structure and growth characteristics of wood, a microphotographic studio and a stone table and shaft for ultracentrifuge apparatus to determine molecular sizes of cellulose and other wood components.

Provision is made for a large timber preservation laboratory, a wood fermentation unit, fractionating stills, a general section of wood chemistry, wood gluing, painting, finishing and fireproofing laboratories, and facilities for the study of wood fungi and insect pests and the abatement of their damages.

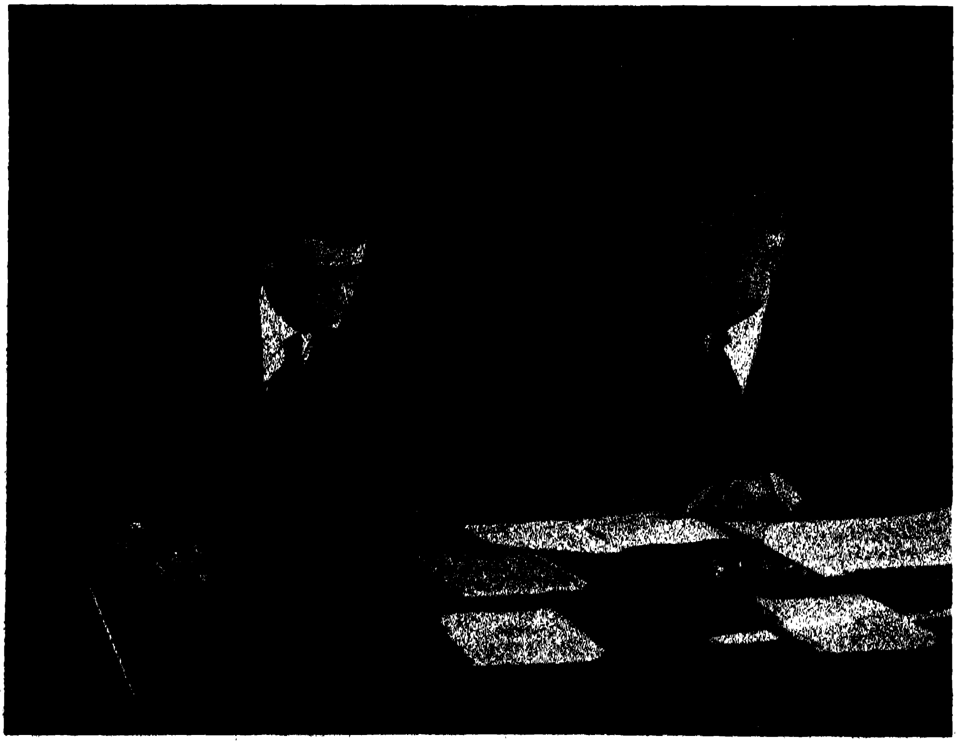
The Forest Products Laboratory is part of the Forest Service of the U. S. Department of Agriculture, which administers the country's greatest reserve of timber, the national forests. "Forestry is concerned not only with timber growing, but also with the efficient use and profitable marketing of forest crops," said Carlile P. Winslow, director of the laboratory, in explaining the purposes of the new building.

"Success in the economic restoration of idle forest and submarginal agricultural lands demands the development of new uses for wood to replace those captured by other materials, the modernizing of existing wood uses and the adaptation of wood to complex and changing requirements. The laboratory will increasingly contribute to these ends through the improved facilities for physical, mechanical, chemical and biological research on wood and other forest products which the new building will afford. The work carried on for several years past by the staff of nearly 200 has taxed available facilities, and since Congress has already authorized the doubling of the annual operating appropriation, the need for new and larger quarters is imperative."

Since the Forest Products Laboratory was opened by the U. S. Department of Agriculture, in 1910, it has occupied buildings owned by the University of Wisconsin. The assistance is based on the original cooperative arrangement whereby the laboratory is available to the university faculty and advanced students for research, and its staff gives lectures in the university on wood chemistry and technology and other subjects related to forest utilization.

The university board of regents has aided the new building project by donating a choice site of 10 acres overlooking Lake Mendota and the university campus.

In general plan the new building will be U-shaped, about 275 feet in length and over-all breadth. It is of modern design, emphasizing "stepped-back" construction, vertical lines and large areas of glass in the external walls. By terms of the Congressional authorization act, the building will be of fireproof construction throughout.



DR. VANNEVAR BUSH

(LEFT) WHO HAS RECENTLY BEEN APPOINTED VICE-PRESIDENT OF THE MASSACHUSETTS INSTITUTE OF TECHNOLOGY AND DEAN OF ITS SCHOOL OF ENGINEERING. DR. BUSH HAS BEEN PROFESSOR OF ELECTRICAL POWER TRANSMISSION AT THE INSTITUTE SINCE 1923. PRESIDENT KARL T. COMPTON IS SEATED AT THE RIGHT

INDEX

NAMES OF CONTRIBUTORS ARE PRINTED IN SMALL CAPITALS

Abel, John J., Portrait, 182
Agassiz Medal Award to Dr. Bigelow, 377
American Association for the Advancement of Science, New Orleans Meeting, 85, 187; President of the, 183
Amphibian in Art and Literature, S. W. FROST, 369
ANDERSON, E., Cyclones, 351
ANDREWS, E. A., An Ant Hill, 97
Animal Grafting, H. H. COLLINS, 261
Ant Hill, E. A. ANDREWS, 97
Ants, Field Study of, W. M. WHEELER, 397
Apollo's Sacred White Mice, C. E. KEELER, 48
Appalachian Trail, B. MACKAYE, 330
Atom, Breakdown of the, A. GOETZ, 125; Weighing the, 481

Battelle Memorial Institute, 475
Beauty and the Science Beast, J. O. PERRINE, 465
BENEDICT, F. G., Reptiles and Human Physiology, 420
BENSON, H. K., Cellulose in Industry, 454
Bergius, Friedrich, Portrait, 280
Bird Migration, A. WETMORE, 459
Birth Control, S. J. HOLMES, 247
Blow-fly Larvae, E. F. ROBERTS, 531
Boas, Franz, Portrait, 84
Bosch, Carl, Portrait, 278
Browne, C. A., Portrait, 86
BUNKER, F. F., "Genes," 556

Caduceus, S. L. TYSON, 492
CALDWELL, M. G., and J. CALHOUN, Culture of the Campas Indians of South America, 238
CALDWELL, R. G., American Panics, 298
Calendar, Simplifying the, C. F. MARVIN, 366; E. B. DELABARRE, 537
Campas Indians of South America, Culture of, M. G. CALDWELL and J. CALHOUN, 238
CANNAN, E., Population, 1831–1931, 147
Cannibalism among the Sharks and Rays, E. W. GUDGER, 403
Cannon, A. J., Award, 379; Portrait, 378
Cause or Chance, P. R. HEYL, 273
Cellulose in Industry, H. K. BENSON, 454
Century, Nuclear, L. W. SHARP, 322
Child Study, A. GESELL, 265
CLARK, A. H., Science and the Radio, 268; The Stars on Our Flag, 469
COLLINS, H. H., Animal Grafting, 261
Continental Shelf, G. T. RUDE, 547
COWLES, H. C., The Ever-changing Landscape, 457
Crops and Civilizations, E. D. MERRILL, 362
Cruelty, Prevention of, M. C. HALL, 211
Cyclones, E. ANDERSON, 351

DARWIN, C. G., Uncertainty Principle, 387
DAVENPORT, C. B., Heredity and Disease, 167
Davis, Bergen, Portrait, 86
DELABARRE, E. B., Simplified Calendar, 537
DENTON, F. M., Why Wave Mechanics?, 195
Depressions and Democracy, W. B. MUNRO, 291
DESCH, C. H., Metals in the Use of Man, 550
DICKINSON, H. C., Liquid Helium, 75
Dinwiddie, A. B., Portrait, 90

Eastman, George, Portrait, 474
Elliott, D. S., Portrait, 90
Erosion, C. L. FORSLING, 311

Flag, The Stars on Our, A. H. CLARK, 469
FLEMING, J. A., The Earth's Magnetic Field, 499
FORSLING, C. L., Erosion, 311
FRASER-HARRIS, D. F., Biology in Shakespeare, 54
von Frey, Max, Portrait, 478; 479
FROST, S. W., The Amphibian in Art and Literature, 369

Gamma-Rays, LORD RUTHERFORD, 483
Geology and Oceanography, W. H. TWENHOFEL, 429
GESELL, A., Child Study, 265
GOETZ, A., The Breakdown of the Atom, 125
Greely, A. W., Portrait, 376
Gregory, William K., Portrait, 87
GUDGER, E. W., Cannibalism among the Sharks and Rays, 403

HALL, M. C., The Prevention of Cruelty, 211
HARDING, T. S., The Metamorphosis of the Horse Doctor, 446
HARRAR, N. J., Washington Sets a River on Fire, 353
Harvard College Observatory, Boyden Station of, in South Africa, 572
Health, Public, and Medicine, C. W. MCCOY, 356
Hedrick, E. R., Portrait, 86
Hegner, Robert, Portrait, 87
Helium, Liquid, H. C. DICKINSON, 75
Heredity, and Disease, C. B. DAVENPORT, 167; and Environment, A. S. PEARSE, 541; the Units of, F. F. BUNKER, 556
HEYL, P. R., Cause or Chance?, 273
HOLMES, S. J., Birth Control, 247
HOPKINS, B. S., Nature's Puzzles, 172
Horn, Ernest, Portrait, 90
Horse Doctor, Metamorphosis of, T. S. HARDING, 446
Human Variations, A. H. SCHULTZ, 360

Ice Manufacture, D. B. KEYES, 176
Indians, Plains, Marriage and Family Life among, R. H. LOWIE, 462
"Instinct" and "Instinctive," R. S. UHRBROCK, 544

JEANS, J. H., Beyond the Milky Way, 35
Johnson, Douglas, Portrait, 87

Karsner, T. Howard, Portrait, 88
KEELER, C. E., Apollo's Sacred White Mice, 48

KEYES, D. B., Ice Manufacture, 176
Kimball, Dexter S., Portrait, 88

Landscape, Ever-changing, H. C. COWLES, 457
Langfeld, Herbert S., Portrait, 88
LAUFER, B., Sino-American Contacts, 243
LEIGHTON, M. M., Prehistoric Men, 77
Life, The Unity of, C. E. MCCLUNG, 259
LINDSAY, R. B., Point of View in Physics, 115
Lowell, Percival, Portrait, 6
LOWIE, R. H., Marriage and Family Life among the Plains Indians, 462
LUKENS, R. R., Oddities of the Ocean, 552

MCCLUNG, C. E., The Unity of Life, 259
MCCOY, G. W., Medicine and Public Health, 356
MACKAYE, B., The Appalachian Trail, 330
Magnetic Field, Earth's, J. A. FLEMING, 499
Marsh, Othniel Charles, Centenary of, 95; Portrait, 94
MARVIN, C. F., Simplifying Our Calendar, 366
Massachusetts Institute of Technology, New Research Laboratories, 473
MERRILL, E. D., Crops and Civilizations, 362
Merrill, E. D., Portrait, 87
Metals, Nature of, E. E. SCHUMACHER, 22; in the Use of Man, C. H. DESCH, 550
Milky Way, Beyond the, J. H. JEANS, 35
MILLER, D. C., The Pipes of Pan, 73
Moore, J. H., Portrait, 86
MUNRO, W. B., Democracy and Depressions, 291
Munro, William B., Portrait, 88

NEWMAN, H. H., Identical Twins, 169
Nobel Prize in Chemistry, 279

Ocean, Oddities of the, R. R. LUKENS, 552
Oceanographic Chemistry, T. G. THOMPSON and E. G. MOBERG, 442
Oceanography of the Pacific, T. W. VAUGHAN, 128
Ostwald, Wilhelm, Portrait, 566; 567

Pan, the Pipes of, D. C. MILLER, 73
Panics, American, R. G. CALDWELL, 298
PEARSE, A. S., Environment and Heredity, 541
Perfumes and Cosmetics, G. M. ZIEGLER, 222
PERRINE, J. O., Beauty and the Science Beast, 465
Physics, R. B. LINDSAY, 115; American Institute of, 287
Pigments, Lead, A. H. SABIN, 31
PINKUS, L. F., A Spider Caught A Snake, 80
Pluto, R. L. PUTNAM and V. M. SLIPHER, 5
Population, 1831–1931, E. CANNAN, 147
Prehistoric Men in the Middle West, M. M. LEIGHTON, 77
Primates, Mentality of, L. A. WHITE, 69
Progress of Science, 85, 183, 279, 377, 473, 566
Pupin, M. I., Portrait, 288
PUTNAM, R. L. and V. M. SLIPHER, Pluto, 5
Puzzles, Nature's, B. S. HOPKINS, 172

Radio and Science, A. H. CLARK, 268
Relativity Theory, M. TALMEY, 41
Reptiles and Human Physiology, F. G. BENEDICT, 420
Rice, E. W., Jr., Portrait, 288
ROBERTS, E. F., Blow-fly Larvae, 531
ROBINSON, L. V., Variable Stars, 343
Rubber from Rocks, 385
RUDE, G. T., The Continental Shelf, 547
RUSSELL, H. N., The Spectroscope, 487
RUTHERFORD, LORD, The Gamma-Rays, 483

SABIN, A. H., Less Well-known Lead Pigments, 31
SCHULTZ, A. H., Human Variations, 360
SCHUMACHER, E. E., The Nature of Metals, 22
Science Service Radio Talks, 73, 167, 259, 356, 454, 547
Shakespeare, Biology in, D. F. FRASER-HARRIS, 54
SHARP, L. W., A Nuclear Century, 322
Sino-American Contacts, B. LAUFER, 243
Social Psychology and Reform, K. YOUNG, 252
Spectroscope, H. N. RUSSELL, 487
Spider and a Snake, L. F. PINKUS, 80
Stars, Variable, L. V. ROBINSON, 343
Switzerland, Water Power in, 381

TALMEY, M., The Relativity Theory, 41
THOMPSON, T. G., and E. G. MOBERG, Oceanographic Chemistry, 442
Thumb, Tom, Three Hundred Years of, H. B. WEISS, 157
TWENHOFEL, W. H., Relation of Geology to Oceanography, 429
Twins, Identical, H. H. NEWMAN, 169
TYSON, S. L., The Caduceus, 492

UHRBROCK, R. S., Popular Usage of the Terms "Instinct" and "Instinctive," 544
Uncertainty Principle, C. G. DARWIN, 387
U. S. Forest Products Laboratory, 574

VAUGHAN, T. W., Oceanography of the Pacific, 128

Warburg, Otto, and the Nobel Prize, 283; Portrait, 284
Ward, Robert DeCourcy, 192; Portrait, 193
Washington Sets a River on Fire, N. J. HARRAR, 353
Wave Mechanics, F. M. DENTON, 195
WEISS, H. B., Tom Thumb, 157
WETMORE, A., Bird Migration, 459
WHEELER, W. M., Field Study of Ants, 397
WHITE, L. A., Mentality of Primates, 69
Williams, C. G., Portrait, 90

YOUNG, K., Social Psychology, 252

ZIEGLER, G. M., Perfumes and Cosmetics, 222

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